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A Colorimetric performance comparison of gray component replacement algorithms

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A Colorimetric Performance Comparison of Gray Component Replacement Algorithms

by

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Colorimetric Performance Comparison of the Gray Component Replacement Functions Used in High-End and Desktop Separations

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Abstract

An experiment was performed to compare the effect of gray component replacement on color separations created with the Hell 399ER scanner software compared to two desktop algorithms. Three different GCR methods were tested; the scanner method where the separations were performed and films output on a mid 1980's model Hell 399ER laser scanner using Hell's first generation GCR algorithm and two types of desktop methods where the scans were done in RGB, color separated on the desktop, and films generated on an Agfa Selectset 5000 imagesetter. The two desktop methods used were RIT Research Corporation's RGB-CMYK transform and Adobe Photoshop 2.0. All scans and proofs were made in the Color Separation Lab at the Rochester Institute of Technology (RIT) in Rochester, New York. The desktop separations were made and film output in RIT's Electronic Prepress Lab.

For each separation method, three levels of GCR were performed; a non-GCR (0%) separation, one at 50% GCR, and one at 80% GCR. In addition, the separations performed on the Hell Scanner were done with Under Color Addition (UCA) off and on.

After separation, the scans were output to film and proofed using 3M Matchprint II. Two proofs were made. One contained the six separations

performed on the Hell scanner and the other contained the six separations made using the desktop software. The proofs were then measured using a spectrophotometer and the results compared using the L*a*b* color space. All color comparisons were done using the non-GCR separation as the color reference. Each ΔE* measurement represents the color difference between a patch on the non-GCR target and the corresponding patch on the target produced using GCR.

The result of the experiment was the rejection of the stated hypotheses that there would be no significant color difference between the output produced from the scanner separations and the desktop separations at two levels of GCR.

The experiment showed that the algorithms used to perform GCR on the desktop produced less color variation than the algorithm used in the Hell 399ER scanner at both 50% and 80% GCR. The results also showed that in almost every case, the amount of color variation increased as the level of GCR was raised. It could not be determined whether or not Under Color Addition (UCA) had any significant influence on color variation for the separations performed on the Hell scanner.

Based on the results of this experiment, color professionals using a desktop production workflow should be encouraged to take advantage of the benefits of GCR without fear that the color of the reproductions will be compromised.

Chapter One

Introduction

The 1988 SWOP handbook defines gray component replacement (GCR) as "...a technique for removing from the color separations some or all of the cyan, magenta, and yellow that produces the gray component of a picture. The gray darkening amounts are replaced by increasing the black printer content in the same area. Simply stated, GCR uses black to create most of the image shape and detail."[1] GCR has great value to the printing industry by reducing many of the problems associated with the multiple layering of ink on paper. As the prepress industry moves toward the less expensive and less proprietary world of the desktop, it will be necessary for desktop hardware and software to produce quality comparable to their high–end competition.

The theory behind gray Component Replacement (GCR) has been around for over 50 years,[2] but until only recently, the technology required to perform the procedure has been lacking. Most of today's high-end digital scanners have GCR algorithms built in, and the technology is now available in desktop prepress software. With the ability to produce GCR separations at the fingertips of anyone who purchases image manipulation software, it is important to examine the effectiveness of GCR separations performed on desktop as well as high–end systems.

The main focus of this study was to quantitatively determine the performance of some of the GCR algorithms used when making color separations. An experiment was performed to determine the color differences produced at varying levels of GCR for both desktop and high–end electronic prepress paths. Since GCR is an alternative to traditional electronic color separation, it was important to determine whether or not separations which utilize GCR produce significant differences in the printed result than traditional color separations. For a given area on an original, there should be no perceptible color difference between a final output produced with traditional versus GCR separations. Since there is inherent variability in the printing process, no reproduction will be a perfect color match to the original, but it is important to know if the method of separation unduly influences that variability.

GCR is a theoretically sound procedure, but if the algorithms used to perform it are substandard, then the separator cannot adequately utilize it, and the printer will lose the benefits inherent in the GCR process.

Endnotes for Chapter One

1 SWOP Handbook, p. 17, 1988.

2 John Yule, "Four Color Processes and the Black Printer," *Journal of the Optical Society of America*, No. 30, p. 322, 1940.

Chapter Two

Theoretical Background

Subtractive Color Theory

The basis of color printing is the reproduction of an original by the layering of colored inks on a substrate. Traditionally, this has been accomplished with the use of three process inks and a black skeleton printer. The process inks are the three subtractive primaries–cyan (c), magenta (m), and yellow (y).

According to subtractive color theory, these three inks should each completely absorb one-third and reflect the remaining two-thirds of the visible spectrum. The cyan ink should absorb all incident red light, the magenta ink should absorb all incident green light, and the yellow ink should absorb all incident blue light. In order to produce a desired color, one would overprint two or three of the primaries. For example, a red would be produced by overprinting magenta and yellow inks. Black would be produced by a solid overprint of all three primaries. In reality, the light absorbing characteristics of the pigments used in the formulation of printing inks do not perfectly match the theoretical model. Fig. 1 shows spectral reflectance curves for both theoretically ideal inks and sample process inks. Because of the unwanted absorption of the printing pigments, the overprint of the three primaries

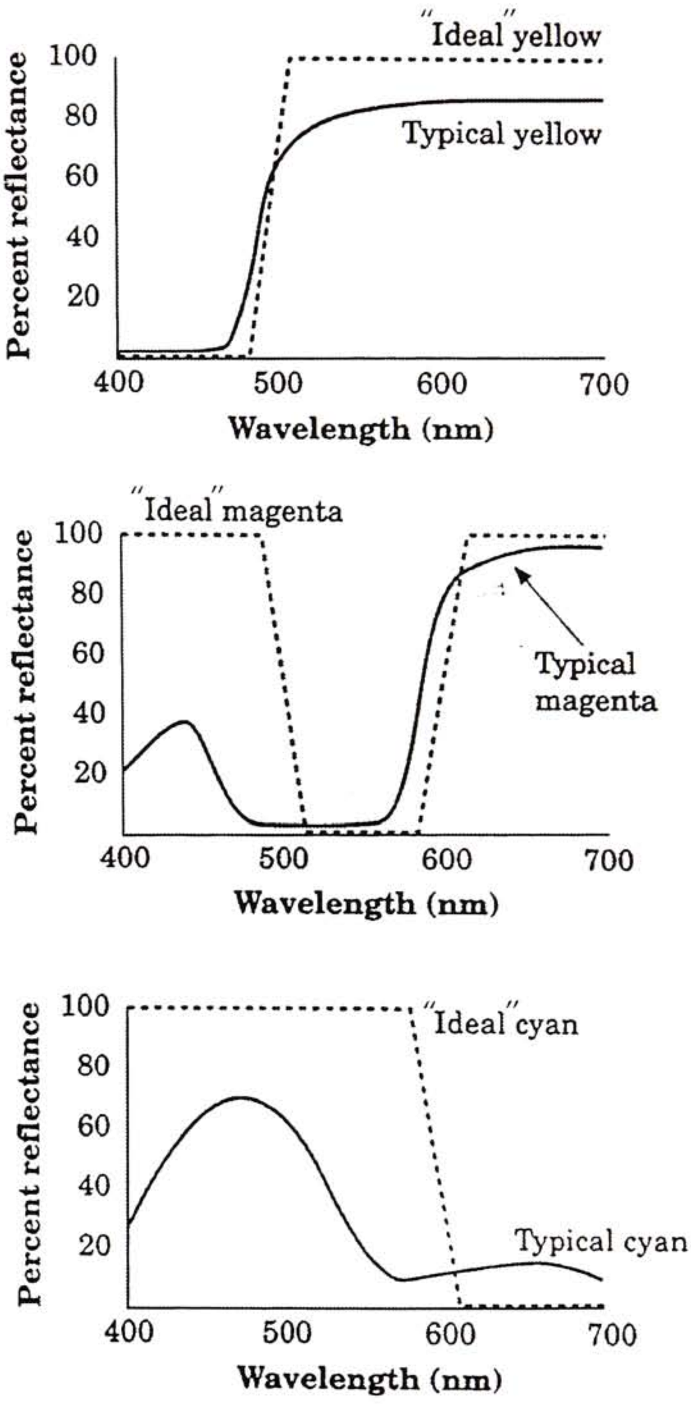

Fig. 1 - Spectral reflectance curves for "ideal" and actual process inks.

produces a muddy brown instead of neutral black. This led to the introduction of black ink into the printing process. Black ink is used to increase the tonal range of the reproduction and to ensure that a neutral black is produced in the shadows.

The addition of the black printer to the reproduction process led to a separation technique called under color removal (UCR). UCR was developed to make room for the black printer in the neutral shadow areas. It is the reduction in dot size of the process colors where the black prints and is used to compensate for the addition of a black ink layer in the neutral shadows.

GCR : Simple Model

An important aspect of process color theory is that a graying component is produced when the three primaries are overprinted. Further, with

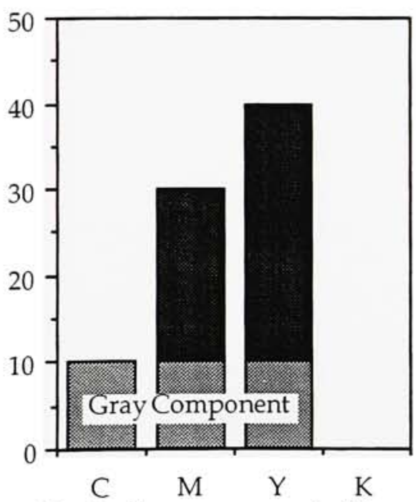

Fig. 2 – Gray component of 3 color overprint (simple model).

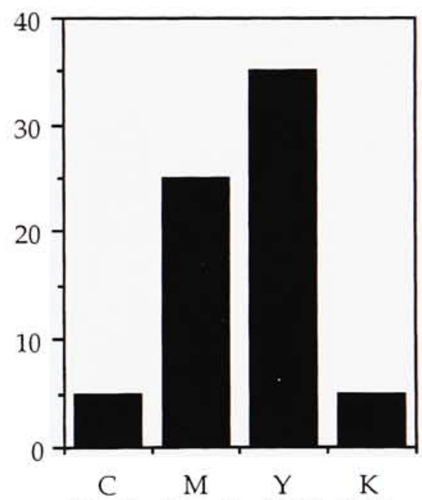

Fig. 3 – Result of 50% GCR separation (simple model).

the ideal inks described previously, when three colors with the same dot area are overprinted, the result is a neutral (in actuality, this is not the case and will be explained later). The size of the dot determines the lightness of the neutral. For example, the overprint of 50% cyan, magenta, and yellow dots should produce a neutral gray tint. In theory, this same tint may also be created by printing just a 50% black tint. This fact lead to the observation by John Yule in 1940 that, "if suitable corrected negatives could be made easily, the best results would usually be obtained by using the maximum quantity of black, and printing not more than two of the three subtractive colors at any one point. A brown, for instance, would be rendered by magenta, yellow, and black in suitable proportions." [1] According to this theory, when any three colors are overprinted, the color with the smallest dot size, combined with equal portions of the other two colors, is the graying component of the overprint. This is demonstrated in Fig. 2.

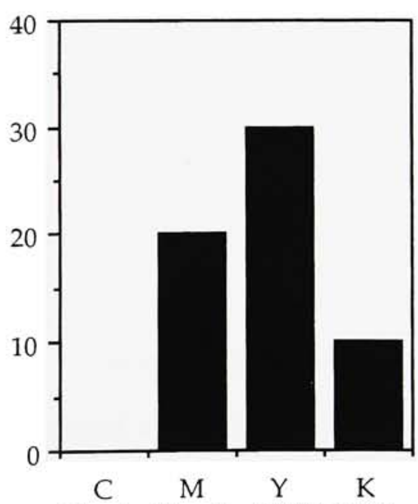

Fig. 4 – Result of 100% GCR separation (simple model).

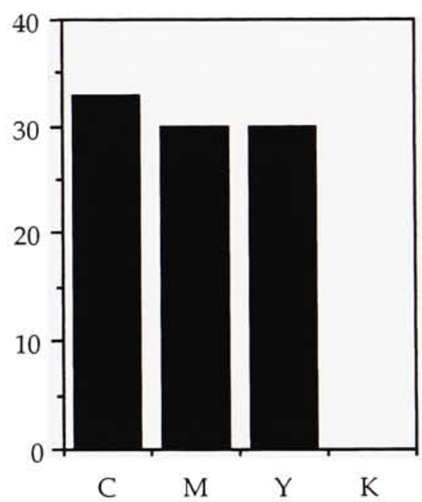

Fig. 5 – Near neutral test patch

In the example, the gray component is the 10% cyan dot, combined with 10% magenta, and 10% yellow. When a separation is made using the GCR technique, some or all of the gray component is replaced with black ink. The amount of GCR can be varied depending on the requirements of the reproduction, and is expressed as a percentage of the gray component replaced with black ink. Fig. 3 and Fig. 4 demonstrate GCR separations of 50 and 100%.

It may be noted that in a 1986 study, Gary Field determined that at high levels of GCR, color variations increased.[2] SWOP recommends the use of GCR at levels of 50 to 80%. These levels ensure that the printer receives the benefits of GCR while avoiding the increased variability produced at high levels of GCR. Also, at 100% GCR the solid ink density in the shadows may fall off as four ink layers have been replaced by only one black ink layer. Under color addition (UCA) may be necessary to restore acceptable shadow densities.[3]

GCR : Real Model

As was discussed earlier, the inks used in printing do not match the ideal theoretical inks described in simple subtractive color theory (see Fig.1). Currently, all process inks have some unwanted absorption characteristics in some part of their spectral curves. This fact has great importance when one tries to formulate an algorithm for producing effective GCR separations.

In the simple theoretical example (Fig. 2), the graying component is produced when equal dot sizes of all three colors are overprinted. In reality, the unwanted absorptions of the process inks throw this gray balance off somewhat. For any given ink set, gray balance tests must be performed in order to determine the actual combination of dot sizes required to produce a true neutral. For most process inks, the cyan dot must be larger than the yellow and magenta dots. This phenomenon must not be overlooked if GCR is to be implemented correctly.[4]

The following example should help to illustrate the danger of using a simple GCR model in a near neutral area of a reproduction. Fig. 5 (page 7) represents a near neutral patch consisting of a 33% cyan, a 30% yellow dot, and a 30% magenta dot. A gray balance test performed for these particular printing conditions has shown that for a 33% cyan dot area to produce a neutral, the corresponding magenta and yellow dot areas would be 27%. Therefore, the gray component is 33%C, 27%M, and 27%Y (Fig. 7) with the hue information carried in the 3%M and 3%Y.[5] From this information, it is ascertained that this patch is near neutral with a slightly reddish cast. If this were separated using the simple model at 100% GCR, the 30% portion of all three colors would be replaced with a 30% black tint (Fig. 6).

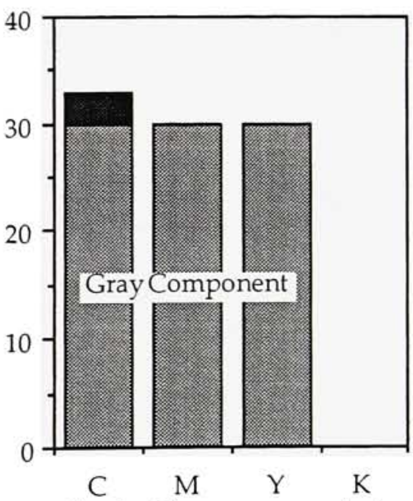

Fig. 6 – Gray component of test patch (simple model).

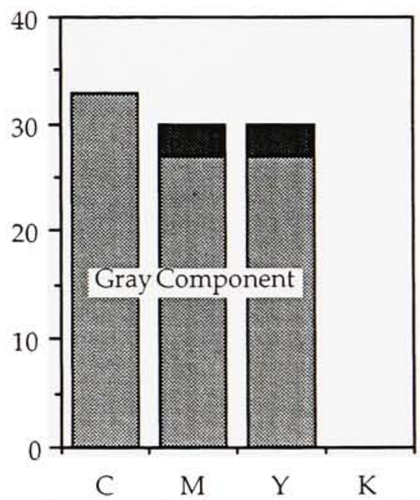

Fig. 7 – Actual gray component determined by gray balance test.

The result is a two color overprint of cyan and black (Fig. 8), which would produce a near neutral with a slight cyan cast.

Fig. 9 represents the result of the GCR separation if the gray balance information is considered. It produces a near neutral with a reddish cast, which was the expected result. The simple model's failure to consider the impurities in the inks prevents proper reproduction of neutral areas. Consequently, it is imperative that any GCR model includes the necessary gray balance information for the printing conditions to be used in the final reproduction.[6]

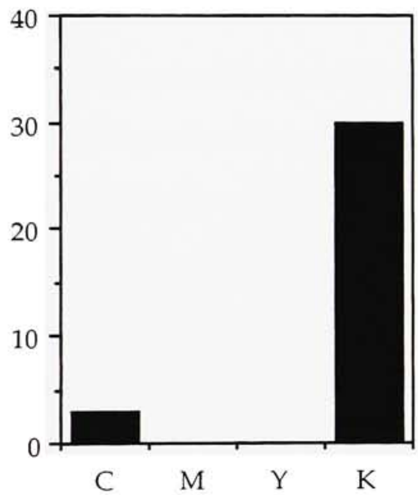

Fig. 8 – Result of simple GCR separation.

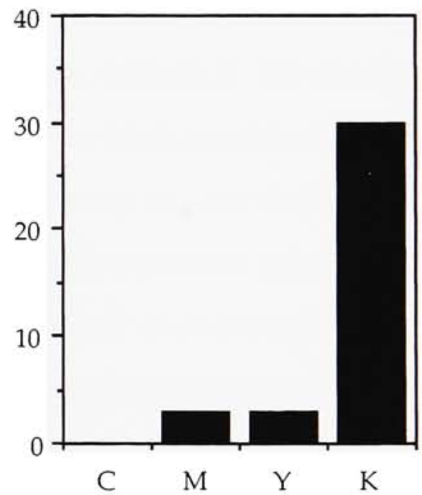

Fig. 9 – Result of GCR separation taking gray balance into consideration.

The Benefits of GCR

Gray component replacement is an important issue in the printing industry because of the benefits it is capable of providing to the printer. Some of the claimed benefits were scrutinized in Dr. Abdel Ghaney Saleh's 1984 paper, "Investigation into the Application of Achromatic Synthesis to the Printing Industry."[7] The most important benefit of GCR discussed is the reduction in sensitivity to color inking fluctuations. When GCR is used, the neutral tones are produced with mostly black ink, therefore, there should be little or no color fluctuation in the gray tones. This is a much more stable condition than in traditional printing where neutral tones are produced with the overprint of the three process inks. In traditional printing, ink fluctuations or changes in dot size (gain or sharpening) may upset the gray balance leading to visible and unwanted hue shifts. Therefore, it is imperative that the ink film thickness is carefully controlled over the entire press run. Since, with GCR, the neutral tones are produced with mostly black ink, a change in the black ink film thickness or in the black dot area affects only the lightness. There is no shift in hue and gray balance is maintained much more easily. This is a crucial point as only a slight hue shift in a neutral is very noticeable to an observer. A direct benefit of this is, with GCR, the press may be brought into color and gray balance much more quickly with corresponding reductions in make-ready time and paper waste.

Another advantage attributed to GCR printing is the lessening of ink trapping problems. With the reduction of the amount of ink being put down in any given area, wet-on-wet trapping problems should be reduced when compared to conventional printing.

Another benefit is the fact that there is one less layer of ink to trap when the GCR method is utilized, since the most ink layers printed would be two colors plus black, as opposed to a four color lay-down.[8]

There are many other benefits attributed to GCR that are mostly the direct result of the decrease in the amount of ink being put on paper. These were presented in Michael Bruno's 1985 article in American Printer entitled "Achromatics : Four Color Printing That Isn't," [9] and include :

- sharper printing due to all detail being in the black;
- reduced metameric variations under different light sources;
- less ink consumption;
- reduced drying problems—less energy needed for ink drying;
- higher printing speed;
- the ability to use lighter weight papers (the reduced ink film thickness should produce major benefits to newspaper printing);
- less dot gain and higher print contrast;
- reduced spray powder requirements in sheet fed printing;
- better ink receptivity.

With the obvious benefits GCR separations afford the printer, it is apparent that the procedure will continue to gain acceptance and importance throughout the industry.

Color Measurement

When an experiment is performed, the results must be measured in a quantitative manner. In the printing industry, color information has traditionally been obtained using densitometric measurements. Densitometers cannot, however, perceive color in the same way as the human eye does due to the spectral sensitivities of the filters they use.[10] "Densitometer readings with the conventional filters are therefore unsuitable for accurate specification of printing ink colors unless it is certain that the same pigments are always used. Even then, errors may result from the fact that densitometers differ in spectral sensitivity."[11]

Color matching information can be more accurately measured using devices that measure the spectral characteristics of the objects being compared. This information can be used in its raw form (spectral reflectance curves) or can be transformed into units that relate color difference in a more intuitive manner (colorimetry).

Colorimetry attempts to include all of the factors that affect the way a reproduction appears to an observer including spectral information from the printed sheet, the illuminant used to observe the object, and a standard observer which approximates the human visual response system. The color space used in this experiment is the CIELAB color measurement system. Information concerning the theoretical background of this system is well documented elsewhere, so I will not go into great detail here. A brief explanation of how the system was used in relation to this experiment will suffice.

In order to use CIELAB, samples are measured using a colorimeter or spectrophotometer. A spectrophotometer gathers spectral reflectance

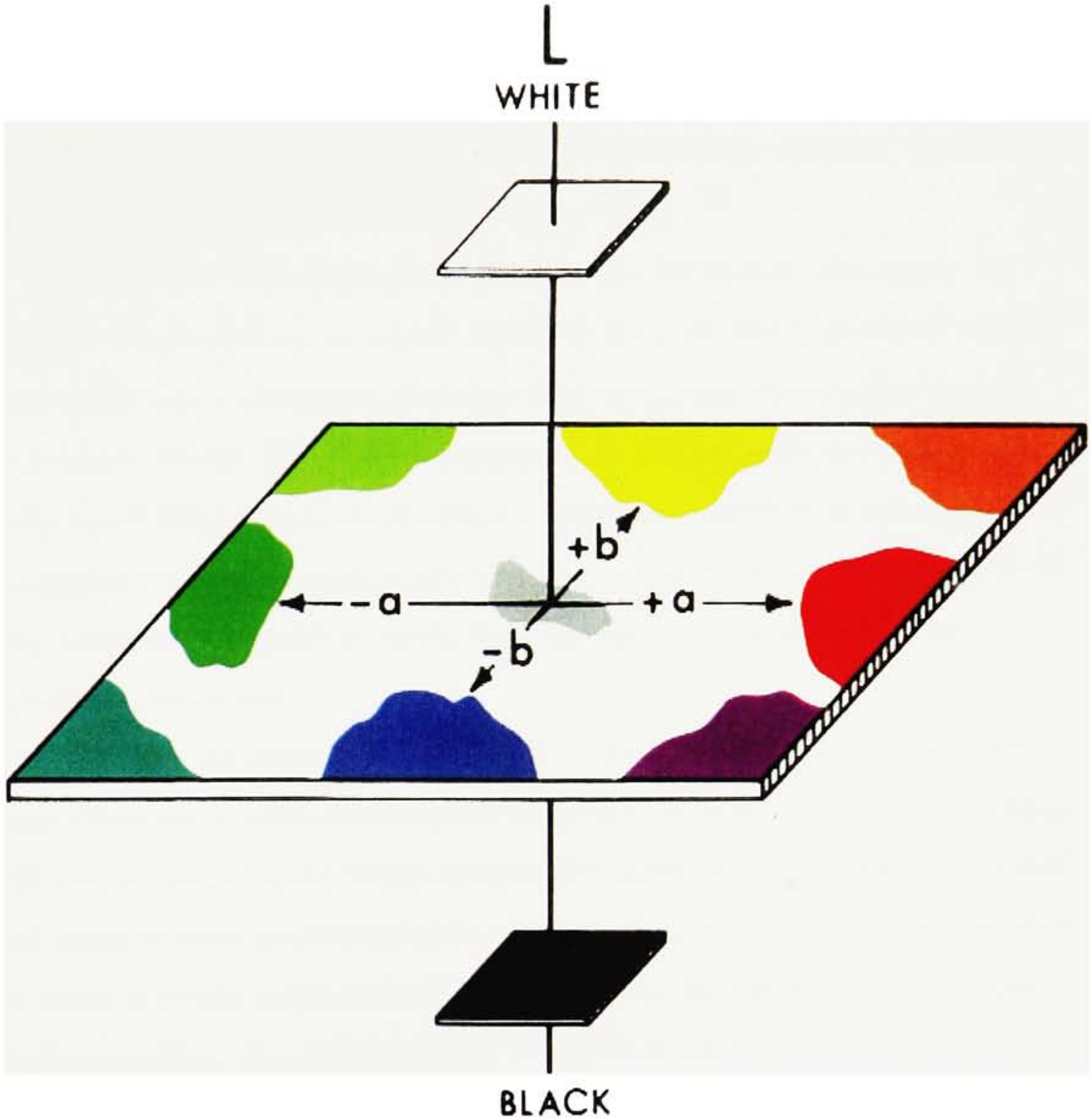

Fig. 10 - Representation of CIELAB's color space.[12]

information about the sample. This information may then be transformed into colorimetric values. A colorimeter is a device that is designed to "see" color the same as the human eye. The output from a colorimeter is in the units of a color space which may be selected according to the needs of the operator. In CIELAB, the output is in the form of L*, a*, and b* coordinates.[13]

The L*a*b* values represent coordinates in the chosen color space. L* provides information on an object's lightness and runs from zero (black) to one hundred (white). Information about an object's hue and chroma are carried in its a* and b* values. The a* value represents the object's redness or greenness, while the b* value represents the object's yellowness or blueness (see Fig. 10).[14] A negative a* value indicates a green hue and a positive a* value indicates a red hue. Likewise, a negative b* value indicates blue and a positive b* value indicates a yellow hue.

Chroma information is also carried in the a* and b* values. The closer these values are to zero, the closer the object is to neutral. A truly neutral object will always have a* and b* values of zero. For example, if an object is measured and found to have coordinates of $L^* = 80$, $a^* = -50$, and $b^* = -50$, it is known that the object is bright, saturated, and has a cyan hue. A hypothetical gray object might have CIELAB coordinates of $L^* = 30$, $a^* = 0$, and $b^* = 0$.

Since color coordinates represent points in a color space, color differences between objects can be determined by calculating the distance between the object's color coordinates within the defined color space. These color differences are expressed in units of ΔE^*, which can be calculated using the following equation:

$$\Delta E^* = \{(L^*_O - L^*_R)^2 + (a^*_O - a^*_R)^2 + (b^*_O - b^*_R)^2\}^{1/2}$$

where L^*_O, a^*_O, and b^*_O are the color coordinates of the original and L^*_R, a^*_R, and b^*_R are the color coordinates of the reproduction.

The following example will illustrate how ΔE^* is calculated and how it is useful to the printer. A test patch on a color proof is measured with a colorimeter and is found to have the following color coordinates: $L^* = 65$, $a^* = 44$, $b^* = 27$. The job is then printed and the same test patch on the press sheet is measured. Its coordinates are: $L^* = 62$, $a^* = 45$, $b^* = 29$.

In order to determine the color difference between the proof and the press sheet, the color coordinates are plugged into the equation above.

$$\Delta E^* = \{(65 - 62)^2 + (44 - 45)^2 + (27 - 29)^2\}^{1/2}$$

$$\Delta E^* = \{(9) + (1) + (4)\}^{1/2}$$

$$\Delta E^* = \{14\}^{1/2}$$

$$\Delta E^* = 3.74$$

Once the ΔE^* value is known, it is used to determine how effectively the reproduction process has matched the color of the original. A ΔE^* value of one is called a just noticeable difference (j.n.d.) which represents the threshold where the human visual system begins to perceive color differences.

The colorimetric system of measurement is a powerful tool for both quality control and for determination of process capability.

Endnotes for Chapter Two

1 John Yule, "Four Color Processes and the Black Printer," *Journal of the Optical Society of America,* No. 30, p. 322, 1940.

2 Gary Field, "Color Variability Associated with Printing GCR and Color Separations," *1986 TAGA Proceedings,* p. 145.

3 SWOP Handbook, 1988 Edition, pp. 17–18.

4 J.A.S. Viggiano, "GCR: A Practical Approach," *Advance Printing of Conference Summaries, SPSE 43rd Annual Conference, April 20–25, 1990,* Springfield,Virginia: Society for Imaging Science and Technology, p. 204.

5 Viggiano, p. 205.

6 Dr. Abdel Ghany Saleh, "Investigation into the Application of Achromatic Synthesis to the Printing Industry," *1984 TAGA Proceedings,* pp.152–157.

7 Saleh, p. 157.

8 Saleh, p. 159.

9 Michael H. Bruno, "Achromatics: Four Color Printing That Isn't," *American Printer,* January 1985, p. 40.

10 M.L. Pearson and J.A.C. Yule, "Conversion of a Densitometer to a Colorimeter,"*1972 TAGA Proceedings*, p. 389.

11 Pearson and Yule, pp. 389–390.

12 Fred W. Billmeyer Jr. and Mark Saltzman, *Principles of Color Technology* , John Wiley and Sons, New York, NY: 1981, Plate IV.

13 Gary Field, *Color and Its Reproduction*, Graphic Arts Technical Association, 1988, p. 54.

14 Field, p.56.

Chapter Three

Review of the Literature

GCR is a topic which has been widely written about and researched. The literature most often cited and most important to this particular study is Dr. Abdel Ghany Saleh's "Investigation into the Application of Achromatic Synthesis to the Printing Industry," found in the *1984 TAGA Proceedings* (p. 151). In this article, Dr. Saleh discusses the history of GCR and the theory behind it. He also mentions the importance of gray balance to the proper performance of GCR and investigates some of the claimed benefits associated with the GCR method of color separation.

In J.A.S. Viggiano's 1990 paper, the importance of gray balance in determining the gray component is discussed. It is an important concept to understand if one is to perform GCR effectively.

Another important resource has been Gary Field's TAGA paper "Color Variability Associated with Printing GCR and Color Separations," found on page 145 of the *1986 TAGA Proceedings*. In this study, it was found that GCR separations are colorimetrically comparable to normal separations, provided that the level of GCR is low. At high levels of GCR, color variability increased.

Much of the color measurement information was obtained from the book *Color and Its Reproduction* written by Gary Field for the Graphic Arts Technical Association (GATF). It includes information on the various color spaces being used in the graphic arts industry and their merits.

These resources are the most important to this study. Other citations are located in the endnotes and the bibliography.

Chapter Four

Hypotheses

Gray component replacement has become widely accepted in the graphic arts industry. As the technology to perform GCR separations becomes more accessible through desktop software, it is important that the effectiveness of the desktop algorithms is investigated.

This experiment measured the effectiveness of three current algorithms used to perform GCR separations. These are: Adobe Photoshop (desktop), R.I.T. Research Corporation's RGB–CMYK transform (desktop), and Hell's first generation GCR algorithm incorporated in its 399ER laser scanner (high-end).

Color separations were produced using three levels of GCR (0%, 50%, and 80%) by each algorithm. Using each algorithm's non-GCR separation as the reference, color variation due to the change in the level of GCR was then determined for each algorithm. In this manner, color differences produced by the use of the different hardware was eliminated. Only color variation produced by changing the GCR level for each separation was examined.

Due to time limitations, the separations were not printed on press, but were output using 3M's Matchprint II proofing system. There are other scanners and software packages that perform GCR, but they were not included in this experiment, also due to time and logistical considerations.

Hypotheses

H1: There is no significant color difference, measured in ΔE^* units, between the non-GCR and 50% GCR separations produced using a Hell 399 scanner, Adobe Photoshop, or RIT Research Corporation's RGB-CMYK transform.

H2: There is no significant color difference, measured in ΔE^* units, between the non-GCR and 80% GCR separations produced using a Hell 399 scanner, Adobe Photoshop, or RIT Research Corporation's RGB-CMYK transform.

Chapter Five

Methodology

An experiment was performed to investigate the performance of some of the GCR algorithms used in desktop and high–end scanning systems.

The first step in designing the experiment was the choice of a test target. The target needed meet certain criteria in order to provide useful information about the GCR algorithms used. These criteria were:

- The target must have a neutral scale made up of cyan, magenta, and yellow to test the effect of GCR on neutral areas.
- The target must have a wide variety of common hues including skin tones and memory colors.
- The target must have both three–color and two–color patches to ensure that the GCR is working where it should be (three–color), and is not working where it should not be (two–color).
- The target must be laid out in an orderly and systematic fashion to facilitate measurement.

The test target used for this experiment was the Kodak Q60A Color Target. (Fig. 11). The Q60A was specifically designed as a color scanner evaluation target and meets the criteria listed above.

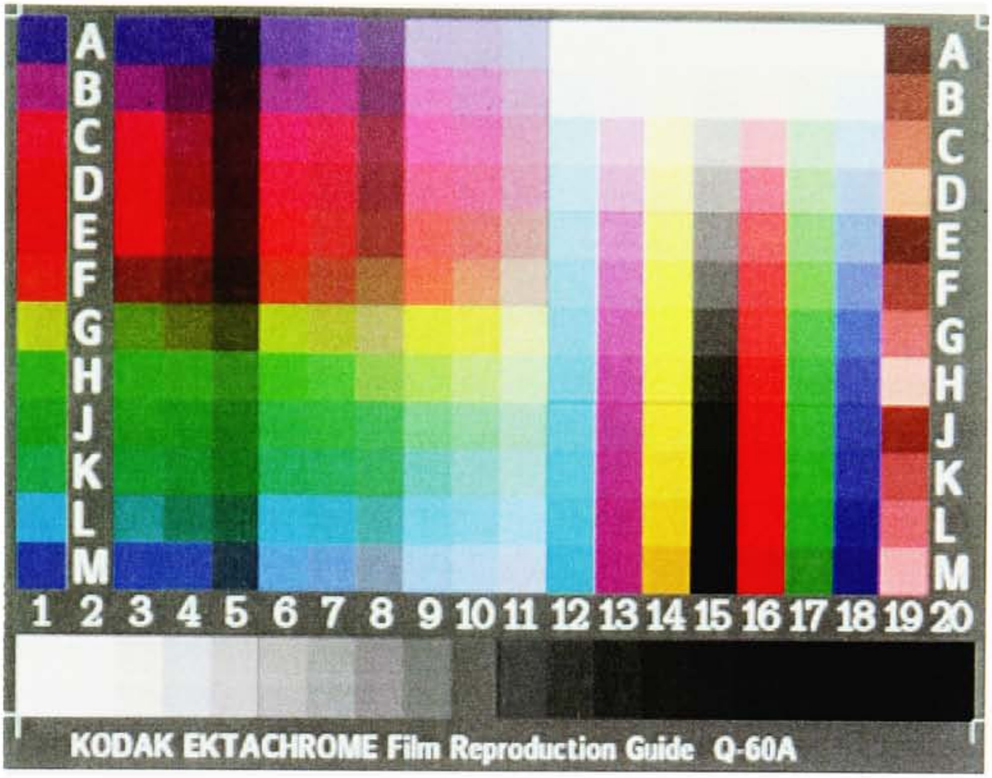

Fig. 11 - Q60A Color Scanner Target

It was also engineered using colorimetric mapping to CIELAB aims, which is the color space used for evaluation of the output in this experiment.[1]

The experiment was begun by generating the color separations for each of the systems being examined. Three separations were made within each prepress path; non-GCR , 50% GCR, and 80% GCR. For the high–end path, the Q60A target was scanned on a Hell 399ER color scanner at the desired level of GCR and output to film on the scanner's film recorder. Another set of films were then made on the Hell using UCA in the dark neutral patches of the target to bring the total dot area in the shadows to 300%.

For the desktop path, the Q60A was scanned using an Optronics ColorGetter II scanner linked to a Macintosh Quadra 950. The scan was saved as an RGB TIFF file which was then imported into the image manipulation software for separation. The two programs investigated in the desktop area were Adobe Photoshop and R.I.T. Research Corporation's RGB–CMYK transform.

When performing the separations, a problem arose as there is no standardization among scanner manufacturers and software vendors for producing a specific GCR percentage. For example, the level of GCR on the Hell scanner is controlled using a dial which has a scale from zero to ten, while Photoshop provides the user a choice of five GCR settings: none, low, medium, high, and maximum. R.I.T. Research's software had no such problem as it allows the user to directly input the desired GCR percentage. Since the level of GCR affects the color characteristics of the reproduction, comparisons between the various prepress paths are meaningless unless the GCR percentages are close to being equal. To achieve this, the actual level of GCR produced for a given setting in Photoshop or on the Hell had to be measured.

A method of quantifying the level of GCR produced at the separation stage can be derived using the definition of GCR percentage. GCR percentage can be defined as the amount of the original gray component replaced by black divided by the new gray component (multiplied by 100%). These quantities can be expressed as dot percentages, where the gray component replaced with black is the dot size of the black (k) in the GCR separation. The new gray component is the remainder of the 3-color gray component plus the added black.

The 3-color gray component is expressed as an average of the dot sizes of the cyan, magenta, and yellow in the GCR separation (c+m+y)/3. Given this, the following equation can be obtained:

$$\%GCR = \frac{\text{gray component replaced by black}}{\text{new gray component}} \times 100\%$$

$$\%\,GCR = \frac{k}{(c+m+y)/3 + k} \times 100\%$$

simplifying the denominator gives :

$$\%\,GCR = \frac{3k}{(c+m+y) + 3k} \times 100\%$$

This equation was used to determine the actual percentage of GCR being produced by Photoshop and by the Hell 399 scanner for their respective GCR settings.

In order to calibrate Photoshop, a gray scale was created using the color picker function. The level of GCR being performed on each step of the gray scale was calculated using the above equation. It was determined that none of the standard GCR settings in Photoshop were capable of producing GCR levels of 50% or 80%. To solve this problem, custom GCR curves were constructed to produce 50% GCR and 80% GCR across the entire gray scale.

A similar process was used to calibrate the Hell 399 scanner. A step wedge was mounted on the scanning drum with the GCR function turned on. The scanning light was then manually stepped across the entire wedge while the level of GCR being performed on each step was calculated.

Using this method, it was determined that a setting of 3.5 on the GCR knob produced a close approximation of 50% GCR. A setting of 8 was used to produce the desired 80% GCR.

The desktop separations were then output as film positives on the Agfa Selectset 5000 imagesetter. The films generated from all three systems were then output on commercial base using 3M's Matchprint II proofing system. Two proofs were made. One contained the six separations performed on the Hell scanner and the other contained the six separations made using the desktop software.

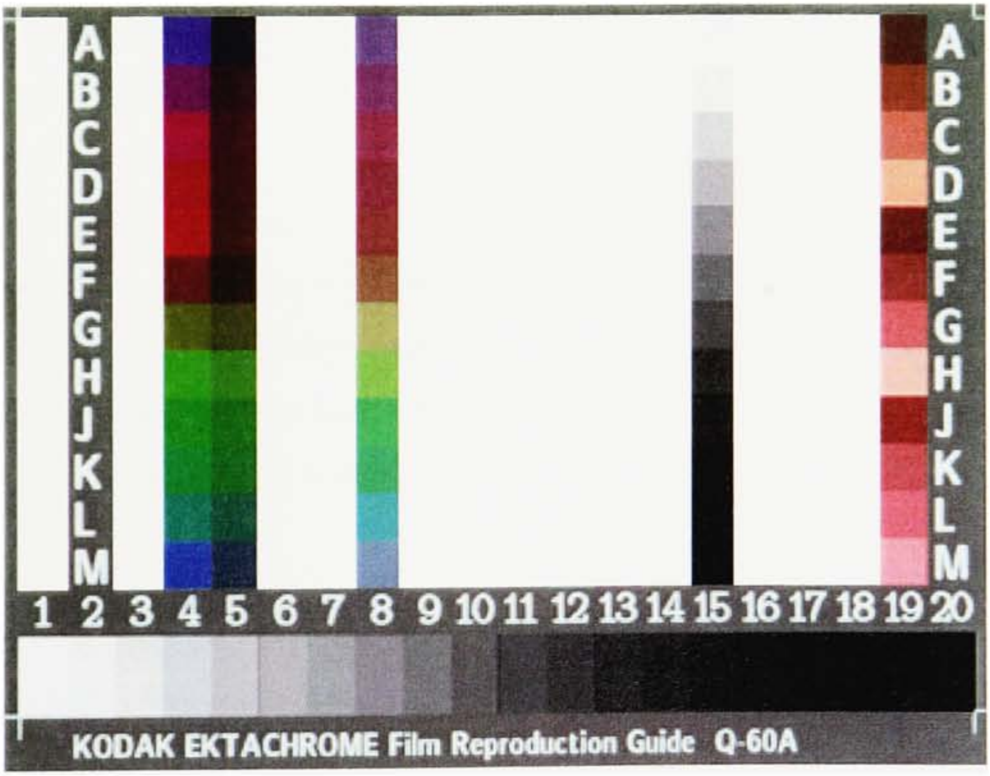

Fig. 12 - Areas of the Q60A target measured and analyzed in this experiment.

Next, the proofs were measured to determine the amount of color variation caused by performing GCR.

For each separation method, the straight scan (0% GCR) was used as the control. The other separations (50% and 80% GCR) were compared to the straight scan to determine the amount of color variation (in ΔE^* units) caused solely by the implementation of gray component replacement. Eighty patches from the Q60A were measured, including all the simulated skin tone patches, all the three-color overprints, and both of the gray scales. (See Fig. 12 on page 27.)

All measurements were taken using a Gretag SPM100 spectrophotometer in the CIELAB color space. The spectrophotometer was set up with the following measurement parameters:

- Illuminant - D50
- Angle - 2°
- Filters - ANSI T
- Polarization - No
- Zeroed to - Reference White

A total of 960 individual measurements were made (12 targets at 80 patches per target) and the data were entered into Microsoft Excel for analysis. The original data is found in Appendix A beginning on page 49.

Endnotes for Chapter Five

1 T.O. Maier and C.E. Rinehart, "Design Criteria foe an Input Color Scanner Evaluation Test Object," *1988 TAGA Proceedings*, p. 469.

Chapter Six

Results

In order to test the stated hypotheses, namely that there is no statistically significant difference between separations performed by the various methods of GCR, the data were measured, entered into a Microsoft Excel spreadsheet, and analyzed using analysis of variance (ANOVA).

ANOVA can be used to test hypotheses in which multiple means (μ_n) of sample populations are said to be equal, i.e. $\mu_1 = \mu_2 = \mu_3$.[1] In this study, the means which were examined are the average ΔE^* values for each of the separation methods in question. For this experiment, eight sample populations were constructed through experimentation. They were analyzed in two groups of four populations. The first group consisted of the four different separation methods at 50% GCR, and the second group consisted of the four separation methods at 80% GCR.

The first hypothesis tested, H1, stated,"There is no significant color difference, measured in ΔE^* units, between the non-GCR and 50% GCR separations produced using a Hell 399 scanner, Adobe Photoshop, or RIT Research Corporation's RGB-CMYK transform." This hypothesis was tested by comparing the mean ΔE^* values for each of the separation methods. The means were tested using a single-factor analysis of variance or ANOVA.

Table 1 below gives a summary of the means and variances of the four separation methods at 50% GCR.

Similarly, the second hypothesis, H2, states that there is no significant difference among the four separation methods at 80% GCR. Table 2 summarizes these data.

Table 1 - Summary statistics of the four separation methods at 50% GCR.

Separation Method	GCR Level	Average ΔE^*	Variance
Hell UCA Off	50%	4.79	4.60
Hell UCA On	50%	4.14	4.60
Adobe Photoshop	50%	1.60	3.14
RIT Research	50%	2.37	2.24

Table 2 - Summary statistics of the four separation methods at 80% GCR.

Separation Method	GCR Level	Average ΔE^*	Variance
Hell UCA Off	80%	6.81	7.78
Hell UCA On	80%	6.04	7.01
Adobe Photoshop	80%	2.06	1.91
RIT Research	80%	2.44	2.98

An in-depth explanation of the derivation of and mathematics behind the ANOVA test are beyond the scope of this discussion, but a brief explanation of how the method was used in this experiment may be useful.

The averages and variances listed in Table 1 and Table 2 are the measured result of the eight different color separation methods tested. Each grouping of data is a sample population or sample. The first hypothesis (H1) states that there is no significant color difference produced by the four separation methods at 50% GCR. Another way to state this hypothesis is to say that the four samples in Table 1 all come from the same general population. The second hypothesis (H2) states that there is no significant color difference produced by the four separation methods at 80% GCR. Likewise, if H2 were true, the four samples in Table 2 all come from the same general population.

The general population in this experiment can be defined as the amount of color variation produced by performing GCR on a color separation. It is assumed that this population follows a normal distribution centered around some mean.

The task is to determine whether the samples we measured are all subsets of this one general population or are members of separate and distinct populations. When ANOVA is performed on multiple sample populations, a statistic, called the F-value, is generated. This F-value follows a mathematically described distribution, and where it falls on that distribution tells the experimenter whether to accept or reject the hypothesis.

If analysis of variance is performed on any number of samples taken from a specific population, then the F-value produced by the test will fall somewhere on the F distribution. The higher the F-value is, the less likely it becomes that all of the samples in question came from the same population. It is therefore necessary to have a cutoff point on the distribution at which the experimenter can reject the hypothesis that all the samples came from the same distribution. The F-value that determines this cutoff is called the critical F-value (F-critical) and is determined by the level of confidence the experimenter wants to achieve, the number of sample populations being compared, and the sample size of each population.

The level of confidence can be described as the probability of rejecting a true hypothesis (α) or of accepting a false hypothesis (β). Obviously, the experimenter would like to minimize the probability of either of these types of error.

In this experiment, the assumption is that the hypothesis is true, so we are at risk of rejecting a true hypothesis. We would then want to minimize the probability of an α error and would select a small α value. However, the smaller the α value is, the larger the F-critical value becomes. The possible consequence of a large F-critical is the acceptance of a false hypothesis.

A way to use the smallest possible α value and minimize the possibility of a β error is to calculate a statistic called the p-value. "The p-value is the probability, given H_0 is true, of the test statistic assuming a value as extreme or more so than the value computed based on the random sample. A relatively small p-value would suggest that if indeed H_0 is true,the observed value of the test statistic is rather unlikely. We would then opt to reject H_0 because that decision would have a higher probability of being correct." [2] In broad terms, the p-value provides reinforcement to the decision on whether to accept or reject the hypothesis in question.

If the p-value is greater than the chosen α, the null hypothesis cannot be rejected.[3] This rule applies even if the F-value returned from the ANOVA is greater than the F-critical value.

The ANOVA analysis was applied to test the two hypotheses (which are restated below), as well as to determine if there is a significant color difference between separations performed at 50% GCR and 80% GCR.

H1: There is no significant color difference, measured in ΔE^* units, between the non-GCR and 50% GCR separations produced using a Hell 399 scanner, Adobe Photoshop, or RIT Research Corporation's RGB-CMYK transform.

H2: There is no significant color difference, measured in ΔE^* units, between the non-GCR and 80% GCR separations produced using a Hell 399 scanner, Adobe Photoshop, or RIT Research Corporation's RGB-CMYK transform.

First, let us examine the first hypothesis, H1. Table 1 gives the average ΔE^* values for the four sample distributions of the 50% GCR separations compared with the corresponding non-GCR separations. If H1 is true, then there is no statistically significant difference between these four samples. Therefore, when ANOVA is performed, we should expect to generate an F-value less than the F-critical value for this sample size and number of samples. We would also expect to see a p-value greater than the α value. The α value chosen for all analyses in this study is 0.05. If these parameters are met, then H1 is accepted.

If and only if the F-value is greater than the F-critical value and the p-value is less than 0.05 will H1 be rejected. Table 3 summarizes the statistics generated from the ANOVA performed on these data.

Table 3 - Descriptive statistics of data taken from separations performed at 50% GCR.

Sample	Sample Size	Sum	Average	Variance
Hell UCA Off	80	383.46	4.79	4.60
Hell UCA On	80	331.29	4.14	4.60
Adobe Photoshop	80	127.75	1.60	3.14
RIT Research Corp.	80	189.77	2.37	2.24

ANOVA statistics for separations performed at 50% GCR.

Source of Variation	Sum of Squares	Degrees of Freedom	MS	F-value	p-value	F-critical
Between Groups	534.18	3	178.06	**48.86**	**5.71×10^{-26}**	**2.63**
Within Groups	1151.55	316	3.64			

The key values from Table 3 (in bold type) are the F-value from the test, the p-value, and the F-critical. For the sets of separations performed at 50% GCR, the F-value (48.86) is significantly greater than the F-critical value (2.63). Also, the p-value is approaching zero. Therefore, I can state with very high confidence that there is a significant difference in the color variation produced by the four separation methods at 50% GCR.

Examination of the data generated from the separations performed at 80% GCR yields the statistics found in Table 4.

Table 4 - Descriptive statistics of data taken from separations performed at 80% GCR.

Summary Statistics of separations performed at 80% GCR.

Sample	Sample Size	Sum	Average	Variance
Hell UCA Off	80	544.42	6.81	7.78
Hell UCA On	80	483.36	6.04	7.01
Adobe Photoshop	80	164.94	2.06	1.91
RIT Research Corp.	80	195.09	2.44	2.98

ANOVA statistics for separations performed at 80% GCR.

Source of Variation	Sum of Squares	Degrees of Freedom	MS	F-value	p-value	F-critical
Between Groups	1422.38	3	474.13	**96.29**	**2.75×10^{-44}**	**2.63**
Within Groups	1555.92	316	4.92			

Once again, the hypothesis, H2, that there is no difference between separations performed at 80% GCR is rejected. The F-value of 96.29 is significantly higher than the F-critical (2.63) and the p-value is essentially zero. I can reject this hypothesis with little chance of rejecting a true hypothesis.

The rejection of the two hypothesis proves that there is a significant color difference between the separation methods. The nature of analysis of variance is to either accept or reject a hypothesis.

In this case, it has been shown that the separation methods are different at the two levels of GCR, but further analysis of the data was necessary to determine the extent of these differences.

GCR Level

Previous studies have indicated that color variation increases as the level of GCR increases. Since this study includes data for GCR performed at 50% and 80%, it seems appropriate to examine this phenomenon.

Table 5 - Summary statistics of the separation methods at 50% and 80% GCR.

Separation Method	GCR	Sample Size	Average ΔE^*	Variance	F-value	p-value	F-critical
Hell UCA On	50%	80	4.79	4.60	**26.14**	**9.06×10^{-7}**	**3.90**
Hell UCA On	80%	80	6.81	7.78			

Separation Method	GCR	Sample Size	Average ΔE^*	Variance	F-value	p-value	F-critical
Hell UCA Off	50%	80	4.14	4.14	**24.90**	**1.58×10^{-6}**	**3.90**
Hell UCA Off	80%	80	6.04	7.01			

Separation Method	GCR	Sample Size	Average ΔE^*	Variance	F-value	p-value	F-critical
Photoshop	50%	80	1.60	3.14	**3.43**	**0.07**	**3.90**
Photoshop	80%	80	2.06	1.91			

Separation Method	GCR	Sample Size	Average ΔE^*	Variance	F-value	p-value	F-critical
RIT Research	50%	80	2.37	2.24	**0.07**	**0.80**	**3.90**
RIT Research	80%	80	2.44	2.98			

Since each separation method was performed at two levels of GCR under otherwise identical circumstances, ANOVA analysis can determine whether the amount of GCR significantly affects the amount of color variation. Table 5 on the previous page summarizes the color difference data as well as the result of the ANOVA test performed on each separation method.

These results show that indeed by traditional separation methods, there is a significant increase in the amount of color variation as the level of GCR is increased. Both sets of separations done on the Hell scanner had an increase of over 2 ΔE^* units as the GCR was increased to 80% from 50%.

Conversely, neither of the desktop separation methods showed a significant increase in color difference as the level of GCR was increased. The amount of increase in ΔE^* was less than 0.5 in both methods. This difference is negligible in visual as well as statistical terms.

Desktop Algorithms vs Hell Scanner Software

Another way to look at the data from this experiment is to break the separation methods into two groups. The separations performed on the Hell scanner and the separations performed on the desktop. Table 6 summarizes those results for both 50% and 80% GCR.

Table 6 - Summary statistics comparing the desktop separation methods with the Hell Scanner separations.

Separation Method	GCR	Sample Size	Average ΔE^*	Variance	F-value	p-value	F-critical
Hell Scanner	50%	160	4.47	4.68	**131.49**	**1.04×10^{-25}**	**3.87**
Desktop	50%	160	1.98	2.82			

Separation Method	GCR	Sample Size	Average ΔE^*	Variance	F-value	p-value	F-critical
Hell Scanner	80%	160	6.42	7.50	**279.58**	**1.79×10^{-45}**	**3.87**
Desktop	80%	160	2.25	2.47			

These data indicate that the separations performed using the desktop algorithms produced less color variation at both 50% and 80% GCR than the separations performed on the high end scanner. The amount of variation in ΔE^* units is 2.49 at 50% GCR and 4.17 at 80% GCR. This magnitude of color difference is visible and would be noticed by an average viewer.

Comparison Of Desktop Systems

The next set of comparisons to make is the two desktop separation methods. Table 7 summarizes these data. This comparison demonstrates that the two desktop separation methods perform similarly. Looking at the separations performed at 50% GCR, Adobe Photoshop performed slightly better with an average ΔE^* 0.77 less than RIT Research Corporation's RGB-CMYK Transform. This difference is significant statistically, but not practically since a ΔE^* below 1.00 is not noticeable to the average observer.

Table 7 - Summary statistics comparing the separations performed by the two desktop methods.

Separation Method	GCR	Sample Size	Average ΔE^*	Variance	F-value	p-value	F-critical
Photoshop	50%	80	**1.60**	3.14	**8.94**	**0.003**	**3.90**
RIT Research	50%	80	**2.37**	2.24			

Separation Method	GCR	Sample Size	Average ΔE^*	Variance	F-value	p-value	F-critical
Photoshop	80%	80	**2.06**	1.91	**2.32**	**0.13**	**3.90**
RIT Research	80%	80	**2.44**	2.98			

At 80% GCR, the two separations performance were indistinguishable both statistically and visually. A hypothesis stating that the two separation methods performed equally would not be rejected using ANOVA (F-value=2.32 and F-critical=3.90), and the color difference represented by the sample averages is 0.38 ΔE^*; below the 1.00 ΔE^* visual threshold.

The Influence of Under Color Addition

At higher levels of GCR, the amount of cyan, magenta, and yellow ink removed from the separations can create a loss of density which cannot be compensated for by the black ink replacing it. This is especially true in the neutral and near neutral areas in the shadows. Under Color Addition, or UCA, can be utilized to minimize this effect. In this study, the high-end scans were performed with both UCA off and UCA on. Table 8 shows the statistical comparison of the two separation methods at 50% and 80% GCR.

Table 8 - Summary statistics comparing the separations performed on the Hell scanner with and without GCR.

Separation Method	GCR	Sample Size	Average ΔE*	Variance	F-value	p-value	F-critical
UCA Off	50%	80	**4.79**	4.60	**3.70**	**0.056**	**3.90**
UCA On	50%	80	**4.14**	4.60			

Separation Method	GCR	Sample Size	Average ΔE*	Variance	F-value	p-value	F-critical
UCA Off	80%	80	**6.81**	7.78	**3.15**	**0.078**	**3.90**
UCA On	80%	80	**6.04**	7.01			

In both cases, the average color difference was slightly smaller for the separations produced using UCA. However, these differences are not statistically significant and the differences, measured in ΔE*, are less than 1.0. As was discussed earlier, a ΔE* of less than 1.0 is not perceptible.

Endnotes for Chapter Six

1. George C. Canavos, *Applied Probability and Statistical Methods*, Boston, MA: Little, Brown & Company, , 1984, p. 376.

2. Canavos, p. 303.

Chapter Seven

Summary and Conclusions

The two stated hypotheses of this study, namely that there would be no difference in the amount of color variation produced by color separations performed on the desktop and on high-end systems at 50% and 80% GCR, were rejected. There were, in fact, significant differences between the methods. In each case examined, the desktop separation algorithms produced less color variation than the GCR software incorporated in the Hell 399ER scanner. It is important to note that this does not reflect the color accuracy of the original scan, only the color variation produced when GCR is incorporated in the color separation procedure.

These results lead to the conclusion that, for production workflows using desktop prepress, GCR is a valuable tool which does not introduce significant color variation to the color separation process.

Further analysis of the data confirmed that indeed there is an increase in the amount of color variation as the level of GCR is increased. These increases are significant on the Hell scanner, but minimal with both desktop separation methods. This finding is consistent with earlier research performed on this subject.

It should be noted, however, that the level at which the color variation increased at high levels of GCR using the desktop methods, was below the visual threshold of most humans.

It was also found that there was no significant difference between the two desktop separation methods, and that the utilization of UCA had no appreciable affect on color variation.

Recommendations for Further Study

Time and budget limitations prevented the test targets for this study to be run on press. The targets instead were output to 3M's Matchprint II, an analog proofing system used to mimic the printing process. It is important to realize that proofing systems (except for press proofs) can only attempt to imitate a press. The effect of platemaking and actual ink on paper is not reflected by this experiment.

The test could be repeated using a newer digital scanner with a more recent GCR algorithm. The algorithm used in the Hell 399ER was an early one and has almost certainly been improved, as have the algorithms currently being used in current desktop separation software.

Also, my skills at running the Hell scanner could be described as at the novice level. I have little doubt that a professional color separator operating one of the new generation of digital scanners could produce better results on the high-end system.

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Appendix A

Original Data

The following pages contain the original L* a* b* data collected from the 3M Matchprint proofs. The data are grouped by separation parameters, which are clearly labeled at the top of each page, and organized by patch ID on the Q60 color target.

Separation Method: Hell Scanner,
UCA Off, 0% GCR

Patch ID	L*	a*	b*	Patch ID	L*	a*	b*
1	91.59	.76	-1.00	J5	36.92	-23.39	16.28
2	88.22	3.93	1.13	K5	37.40	-27.93	12.39
3	82.79	4.98	4.20	L5	39.26	-21.75	-1.95
4	75.98	7.02	2.88	M5	36.89	-2.47	-7.94
5	70.85	6.76	3.43	A8	46.70	11.93	-5.26
6	66.95	6.03	3.74	B8	46.75	23.41	2.16
7	63.55	4.27	3.15	C8	47.11	27.76	11.46
8	58.56	5.74	4.70	D8	46.84	26.77	15.11
9	55.60	2.59	5.10	E8	50.60	22.97	21.56
10	51.73	3.03	6.61	F8	56.36	15.55	27.59
11	47.97	1.94	4.80	G8	68.10	7.17	32.83
12	45.00	1.17	4.86	H8	61.00	-8.38	26.10
13	41.73	-1.30	4.11	J8	56.57	-23.50	17.06
14	37.97	-.99	4.68	K8	53.25	-29.11	12.31
15	34.81	-2.57	4.83	L8	56.56	-21.08	-9.91
16	30.68	-3.62	3.87	M8	53.30	2.15	-7.01
17	25.57	-4.49	2.99	A15	91.47	.85	-2.86
18	22.41	-5.57	1.84	B15	85.36	3.55	2.90
19	19.10	-4.93	1.40	C15	74.66	6.82	5.42
20	11.29	-2.54	-1.46	D15	66.54	7.56	5.74
A4	30.44	8.29	-21.77	E15	59.27	7.29	6.74
B4	31.32	28.59	-6.43	F15	54.28	1.53	4.34
C4	32.59	34.91	-0.17	G15	47.35	2.81	7.55
D4	32.14	31.23	11.60	H15	40.62	.21	6.35
E4	35.95	32.67	20.85	J15	35.17	-1.74	6.93
F4	38.88	17.21	26.25	K15	28.36	-1.83	5.12
G4	47.86	1.51	34.54	L15	21.03	-3.22	2.77
H4	46.41	-28.91	29.81	M15	10.28	-1.88	-1.21
J4	42.23	-45.12	23.64	A19	40.99	15.31	23.17
K4	42.83	-44.56	16.58	B19	52.06	19.63	29.80
L4	45.11	-34.57	-12.99	C19	62.91	21.66	30.37
M4	36.78	-4.32	-26.70	D19	73.35	23.67	30.27
A5	32.19	3.49	-2.80	E19	41.16	18.74	17.87
B5	31.72	14.27	-0.96	F19	51.94	23.72	23.62
C5	31.36	18.86	4.59	G19	62.35	26.42	25.52
D5	31.57	16.75	8.94	H19	76.50	20.45	23.85
E5	36.61	14.10	16.36	J19	45.49	27.26	21.20
F5	38.90	6.86	20.31	K19	56.80	26.25	22.91
G5	45.95	3.74	25.87	L19	61.76	28.19	21.36
H5	43.83	-14.23	20.99	M19	71.64	27.81	20.31

Separation Method: Hell Scanner,
UCA Off, 50% GCR

Patch ID	L*	a*	b*	Patch ID	L*	a*	b*
1	92.54	0.78	-1.29	J5	30.81	-18.80	10.16
2	89.32	3.52	-0.06	K5	30.62	-21.46	7.57
3	83.74	3.93	2.58	L5	35.15	-17.94	-3.66
4	76.80	4.72	0.33	M5	33.84	-1.79	-10.31
5	70.85	3.90	0.25	A8	45.16	10.00	-8.08
6	66.21	3.35	0.48	B8	45.78	20.08	-1.62
7	62.80	1.22	-0.30	C8	45.74	23.92	8.00
8	57.83	2.81	0.47	D8	45.32	23.03	11.84
9	55.41	0.23	0.23	E8	49.24	20.15	18.07
10	50.89	0.52	2.43	F8	56.29	11.23	23.90
11	45.77	-0.77	-0.66	G8	68.40	2.96	30.02
12	42.42	-0.8	-0.23	H8	59.30	-9.78	22.86
13	39.51	-2.55	-1.10	J8	54.14	-23.89	13.57
14	36.01	-2.37	0.60	K8	49.82	-27.33	8.80
15	32.72	-3.29	-0.59	L8	55.11	-20.07	-12.57
16	28.45	-3.22	-0.28	M8	51.70	0.84	-8.88
17	23.80	-3.16	-1.73	A15	92.95	0.19	-2.10
18	18.40	-4.21	-1.65	B15	86.54	2.76	1.53
19	14.63	-2.88	-1.57	C15	75.10	5.07	2.31
20	8.98	-2.26	-2.06	D15	66.33	4.83	2.53
A4	30.25	8.60	-23.14	E15	59.14	3.76	2.30
B4	28.89	24.75	-8.65	F15	54.62	-0.93	0.57
C4	29.16	30.53	-2.83	G15	46.00	-0.14	2.62
D4	28.71	26.35	8.55	H15	40.53	-2.14	0.92
E4	32.71	27.07	16.47	J15	34.11	-3.1	2.69
F4	35.86	13.88	21.62	K15	26.04	-2.32	1.77
G4	46.31	-2.00	32.03	L15	17.18	-2.50	0.66
H4	42.58	-27.53	25.39	M15	9.01	-2.16	-1.69
J4	35.67	-38.76	18.96	A19	39.43	11.85	16.46
K4	35.63	-37.26	12.37	B19	51.76	16.56	24.11
L4	43.12	-32.54	-13.61	C19	63.41	19.00	27.07
M4	36.14	-3.40	-27.70	D19	74.32	23.79	29.89
A5	30.02	3.11	-6.55	E19	39.32	15.40	15.43
B5	29.23	10.44	-3.75	F19	51.05	21.27	21.24
C5	28.52	15.06	1.11	G19	62.07	25.20	23.96
D5	28.53	12.34	5.18	H19	77.62	20.12	23.04
E5	33.81	10.23	11.42	J19	43.88	24.00	18.47
F5	36.26	4.01	13.94	K19	55.87	24.05	20.50
G5	44.77	0.17	20.69	L19	61.15	27.38	19.69
H5	39.87	-14.38	15.22	M19	72.24	28.08	20.10

Separation Method: Hell Scanner,
UCA Off, 80% GCR

Patch ID	L*	a*	b*	Patch ID	L*	a*	b*
1	93.68	0.62	-0.67	J5	30.75	-16.64	8.48
2	91.39	3.24	0.94	K5	30.83	-19.01	5.12
3	86.66	4.22	3.73	L5	37.34	-16.03	-6.46
4	79.41	4.53	0.69	M5	38.21	-3.56	-10.82
5	74.39	2.17	0.30	A8	48.95	9.74	-9.27
6	70.48	1.63	-0.13	B8	48.78	18.65	-2.85
7	68.70	-0.08	-0.68	C8	48.36	22.76	5.85
8	62.74	0.92	0.40	D8	47.77	21.54	9.81
9	60.25	-1.53	-0.86	E8	52.43	19.29	15.71
10	56.19	-1.51	1.08	F8	59.71	9.78	23.24
11	53.50	-2.02	-1.17	G8	71.34	1.79	28.95
12	50.58	-2.09	-1.15	H8	61.97	-9.67	22.27
13	45.75	-3.13	-1.95	J8	55.55	-22.36	12.83
14	42.08	-3.25	-0.88	K8	51.85	-26.26	8.41
15	37.31	-3.45	-1.82	L8	57.69	-19.61	-13.84
16	32.40	-3.58	-1.86	M8	56.39	0.72	-9.83
17	24.94	-3.31	-2.31	A15	93.64	0.19	-2.18
18	20.00	-3.87	-1.58	B15	89.55	2.07	0.67
19	16.36	-3.96	-1.36	C15	79.46	3.14	1.05
20	15.39	-3.62	-2.24	D15	70.71	2.29	0.34
A4	31.39	8.42	-22.27	E15	64.37	0.92	-0.02
B4	30.02	23.09	-7.96	F15	58.00	-2.37	-1.60
C4	29.88	28.45	-2.67	G15	52.91	-1.81	-0.22
D4	28.88	23.76	6.65	H15	45.75	-3.05	-1.11
E4	34.08	25.39	15.45	J15	38.93	-3.76	0.02
F4	38.28	12.54	20.44	K15	29.57	-3.13	-0.61
G4	50.01	-2.99	31.50	L15	19.30	-3.36	-0.81
H4	42.50	-23.86	24.75	M15	15.63	-3.54	-1.80
J4	34.56	-36.72	18.52	A19	43.85	8.81	13.41
K4	34.62	-34.55	9.88	B19	55.57	13.52	22.02
L4	44.05	-30.23	-14.89	C19	66.26	17.07	26.30
M4	37.45	-3.75	-26.13	D19	75.56	22.77	28.40
A5	33.40	0.87	-7.34	E19	41.86	12.87	11.98
B5	32.53	8.38	-4.57	F19	53.65	19.87	19.08
C5	31.68	11.70	-1.26	G19	64.22	24.43	22.37
D5	31.07	10.29	3.32	H19	78.62	19.67	21.86
E5	38.33	7.63	9.47	J19	44.82	22.08	15.75
F5	41.95	1.28	13.35	K19	57.42	23.43	18.83
G5	49.76	-1.61	19.02	L19	63.10	27.37	18.15
H5	42.11	-13.71	13.5	M19	72.85	27.86	19.67

Separation Method: Hell Scanner,
UCA On, 0% GCR

Patch ID	L*	a*	b*	Patch ID	L*	a*	b*
1	90.48	0.80	-0.30	J5	36.21	-24.40	13.99
2	87.17	3.98	1.60	K5	36.35	-27.30	10.32
3	81.38	5.44	4.72	L5	38.48	-20.52	-3.24
4	74.98	7.29	3.30	M5	35.95	-2.59	-7.03
5	69.51	7.19	3.70	A8	46.59	12.14	-8.48
6	65.38	6.45	3.77	B8	46.89	22.93	-0.65
7	61.86	5.37	4.15	C8	46.82	27.36	9.57
8	56.95	6.44	4.99	D8	46.39	26.41	12.61
9	53.96	3.03	4.58	E8	50.53	22.81	19.38
10	50.04	4.05	6.69	F8	56.43	14.74	26.09
11	46.47	2.81	4.41	G8	68.44	4.27	31.06
12	42.97	2.33	4.94	H8	60.71	-10.21	24.73
13	39.94	0.23	4.29	J8	56.14	-24.89	15.45
14	36.67	0.21	5.16	K8	52.74	-30.49	10.48
15	32.66	-1.21	4.78	L8	55.54	-20.80	-11.01
16	28.74	-2.04	3.32	M8	52.13	3.24	-8.16
17	24.77	-3.80	1.48	A15	90.54	1.34	3.27
18	20.35	-4.49	2.26	B15	84.53	3.07	2.05
19	17.57	-3.84	1.80	C15	74.26	6.69	4.03
20	10.41	-2.07	-0.98	D15	65.82	7.00	4.58
A4	31.04	9.12	-26.30	E15	59.26	5.83	4.14
B4	31.47	28.89	-10.95	F15	53.40	1.26	2.64
C4	32.36	34.58	-3.33	G15	46.89	1.69	5.05
D4	31.72	30.29	9.42	H15	39.81	-0.08	2.54
E4	35.85	31.60	18.83	J15	33.98	-1.28	4.61
F4	38.94	15.98	23.67	K15	27.15	-2.32	1.81
G4	48.06	-0.95	33.32	L15	20.40	-2.32	0.89
H4	46.77	-31.25	28.07	M15	10.06	-2.07	-2.12
J4	42.32	-46.08	22.44	A19	40.91	12.68	19.60
K4	41.79	-43.73	16.72	B19	51.87	16.93	26.59
L4	44.55	-34.24	-12.84	C19	62.84	20.13	29.65
M4	35.80	-3.88	-25.34	D19	72.87	22.97	30.83
A5	31.42	3.76	-5.81	E19	40.46	18.00	16.73
B5	31.09	14.95	-3.24	F19	51.06	23.17	23.34
C5	31.31	20.19	2.70	G19	61.39	25.72	24.93
D5	30.84	16.79	7.06	H19	75.56	20.11	23.70
E5	36.39	13.69	14.47	J19	44.39	26.79	20.10
F5	39.01	5.49	17.82	K19	55.84	25.60	22.52
G5	46.11	1.50	23.91	L19	60.19	28.40	21.37
H5	43.79	-15.55	18.30	M19	70.31	28.50	20.52

Separation Method: Hell Scanner,
UCA On, 50% GCR

Patch ID	L*	a*	b*	Patch ID	L*	a*	b*
1	91.40	1.42	-0.46	J5	30.64	-18.66	9.16
2	88.06	3.98	1.25	K5	30.11	-21.16	7.14
3	82.10	4.71	3.93	L5	34.98	-16.95	-3.52
4	74.81	5.54	2.21	M5	33.49	-2.07	-8.69
5	68.80	4.63	1.53	A8	44.31	11.14	-11.04
6	64.86	3.75	1.56	B8	44.76	20.48	-3.53
7	61.14	2.20	1.87	C8	45.03	24.15	5.01
8	56.39	3.50	3.02	D8	44.68	22.70	9.08
9	53.61	0.92	1.91	E8	49.04	19.69	16.16
10	49.14	1.96	4.25	F8	55.90	10.73	22.88
11	44.85	-0.07	1.02	G8	67.62	2.09	29.21
12	41.59	-0.13	1.51	H8	58.62	-10.07	21.70
13	38.72	-1.62	0.18	J8	53.24	-23.80	13.62
14	35.50	-1.30	0.62	K8	49.16	-27.38	8.88
15	31.61	-2.20	1.05	L8	54.48	-19.79	-11.85
16	27.21	-2.34	1.21	M8	50.77	0.99	-8.45
17	22.35	-2.67	0.01	A15	92.25	0.84	-2.03
18	16.88	-2.63	-0.36	B15	85.73	3.16	1.77
19	13.83	-3.12	-0.50	C15	74.62	4.68	1.78
20	8.40	-2.16	-1.44	D15	65.83	4.24	1.91
A4	29.64	11.13	-27.30	E15	58.31	3.61	1.99
B4	28.43	24.89	-11.77	F15	53.30	-0.97	1.09
C4	28.89	30.08	-6.27	G15	45.73	-0.47	1.96
D4	27.92	26.19	5.93	H15	38.98	-1.36	0.81
E4	32.22	26.94	14.12	J15	33.13	-2.42	2.19
F4	35.51	13.22	20.78	K15	25.68	-1.83	0.80
G4	45.58	-2.37	30.57	L15	16.64	-2.65	0.35
H4	41.95	-27.49	24.60	M15	8.10	-2.06	-1.60
J4	35.08	-38.55	17.74	A19	38.78	10.79	14.46
K4	34.73	-36.73	12.12	B19	51.35	15.41	21.37
L4	41.87	-31.42	-13.56	C19	63.19	18.07	25.79
M4	35.25	-2.78	-26.13	D19	74.27	23.02	29.18
A5	29.78	3.30	-8.13	E19	38.02	14.94	12.86
B5	28.50	10.81	-6.15	F19	49.94	20.88	20.02
C5	28.12	14.72	-0.60	G19	61.28	25.49	22.98
D5	28.36	11.85	3.52	H19	76.78	20.54	23.42
E5	33.95	9.43	10.55	J19	42.98	23.96	17.76
F5	36.25	3.53	13.85	K19	55.21	24.28	20.71
G5	43.92	-0.15	20.05	L19	60.17	28.00	20.17
H5	39.72	-13.90	14.01	M19	71.37	29.09	20.33

Separation Method: Hell Scanner,
UCA On, 80% GCR

Patch ID	L*	a*	b*	Patch ID	L*	a*	b*
1	91.25	1.09	-0.12	J5	30.52	-17.53	6.57
2	87.77	3.46	1.24	K5	30.10	-19.46	5.87
3	83.26	4.02	3.57	L5	36.83	-15.81	-6.52
4	77.04	4.44	1.38	M5	35.48	-3.93	-10.32
5	71.47	2.64	0.26	A8	46.46	10.63	-11.76
6	67.63	2.07	0.87	B8	46.27	19.07	-4.78
7	64.45	-0.08	-0.08	C8	46.31	22.91	5.30
8	58.54	1.18	1.11	D8	45.95	21.24	8.15
9	54.63	-0.96	-0.32	E8	50.63	18.18	16.29
10	51.77	-0.90	2.21	F8	57.89	9.04	22.96
11	44.91	-2.29	-0.79	G8	69.60	0.70	29.93
12	40.68	-2.30	0.02	H8	60.72	-11.03	22.09
13	35.54	-3.55	-1.85	J8	53.81	-23.69	13.29
14	31.94	-3.42	-1.07	K8	49.56	-26.37	7.75
15	26.90	-3.82	-1.62	L8	55.42	-19.37	-12.24
16	21.73	-4.48	-1.19	M8	53.98	0.13	-8.76
17	16.51	-4.66	-1.53	A15	92.28	1.22	-1.51
18	12.34	-4.29	-1.92	B15	87.53	2.75	1.65
19	10.03	-4.14	-1.45	C15	76.98	3.83	1.60
20	7.78	-3.29	-2.20	D15	68.10	2.55	0.64
A4	30.36	10.32	-26.46	E15	61.64	1.60	0.51
B4	29.20	23.95	-10.78	F15	54.08	-2.15	-2.11
C4	29.01	27.51	-4.70	G15	47.13	-1.95	-0.58
D4	28.02	23.35	5.80	H15	36.32	-3.80	-1.93
E4	33.33	24.94	14.39	J15	29.80	-4.61	-0.67
F4	38.48	10.76	18.95	K15	19.99	-3.84	-1.16
G4	49.99	-4.36	31.17	L15	12.46	-3.65	-1.52
H4	41.98	-25.65	23.13	M15	9.29	-2.86	-2.63
J4	34.52	-37.86	17.96	A19	42.62	8.92	12.43
K4	34.23	-35.13	11.25	B19	53.37	13.50	21.81
L4	42.42	-30.18	-13.73	C19	65.43	17.43	26.74
M4	36.11	-2.94	-25.34	D19	74.75	22.91	29.60
A5	27.44	1.64	-9.34	E19	41.53	13.20	11.70
B5	28.63	8.47	-6.18	F19	52.07	19.31	18.66
C5	28.99	11.91	-1.32	G19	63.94	24.37	22.35
D5	28.63	9.90	2.06	H19	77.41	20.53	23.00
E5	36.84	6.88	10.00	J19	44.07	22.41	16.48
F5	40.10	0.69	12.37	K19	56.12	23.75	20.22
G5	49.73	-2.71	20.07	L19	61.90	27.74	19.76
H5	42.31	-14.63	11.96	M19	71.79	29.26	20.88

Separation Method: Adobe Photoshop,
0% GCR

Patch ID	L*	a*	b*	Patch ID	L*	a*	b*
1	96.59	0.31	-1.39	J5	43.62	-28.95	17.83
2	93.68	1.66	-1.11	K5	44.64	-30.30	7.29
3	89.43	3.22	0.36	L5	45.56	-22.55	-6.82
4	83.84	3.75	-1.91	M5	43.18	-4.12	-17.10
5	79.22	2.98	-1.66	A8	57.15	11.06	-15.75
6	75.08	2.86	-1.53	B8	56.66	20.78	-7.96
7	70.66	0.86	-2.58	C8	57.21	27.14	0.75
8	65.60	2.01	-1.79	D8	56.18	25.21	5.84
9	61.25	-1.00	-2.14	E8	59.71	20.57	13.14
10	56.82	-1.55	-1.65	F8	64.34	8.85	18.29
11	52.31	-2.49	-1.96	G8	75.23	-1.46	21.75
12	48.28	-1.71	-0.25	H8	69.60	-17.54	18.79
13	44.47	-3.17	1.41	J8	66.66	-30.59	10.31
14	39.87	-1.96	3.08	K8	63.22	-31.92	3.59
15	34.83	-2.42	4.47	L8	63.83	-22.70	-12.70
16	29.73	-1.39	7.48	M8	62.51	-1.94	-14.59
17	23.20	-0.41	3.84	A15	96.64	-0.03	-1.14
18	17.26	-0.17	0.92	B15	91.29	2.42	0.69
19	13.62	0.31	-0.99	C15	83.01	3.34	-0.78
20	8.67	-1.94	-1.84	D15	75.52	3.25	-0.74
A4	39.55	19.07	-34.26	E15	67.12	2.62	-1.54
B4	40.29	41.41	-17.26	F15	59.41	-1.20	-3.01
C4	43.97	50.18	-0.87	G15	52.39	-1.57	-0.68
D4	43.08	45.71	28.20	H15	43.56	-1.82	1.22
E4	45.17	44.83	34.61	J15	35.85	-2.14	6.26
F4	41.35	22.19	30.11	K15	25.63	0.05	7.18
G4	50.99	-7.98	36.47	L15	15.57	1.54	0.13
H4	54.58	-35.11	33.91	M15	8.87	-1.86	-1.91
J4	47.26	-43.34	24.21	A19	47.77	14.48	19.28
K4	48.13	-41.61	8.74	B19	60.38	17.18	20.25
L4	47.44	-29.12	-14.31	C19	72.82	17.46	19.57
M4	45.40	-0.03	-37.79	D19	82.19	16.93	19.56
A5	36.57	7.73	-12.83	E19	47.96	20.39	17.69
B5	36.46	18.77	-7.00	F19	60.54	23.03	18.13
C5	37.48	25.93	3.23	G19	72.92	22.90	15.94
D5	36.32	23.09	13.30	H19	84.84	14.92	14.27
E5	40.89	14.37	19.02	J19	52.85	28.99	21.86
F5	41.74	3.43	23.08	K19	66.09	25.72	14.50
G5	51.33	-5.89	24.46	L19	71.99	26.27	12.49
H5	52.85	-23.68	21.35	M19	81.20	22.62	11.99

Separation Method: Adobe Photoshop,
50% GCR

Patch ID	L*	a*	b*	Patch ID	L*	a*	b*
1	96.96	-0.41	1.36	J5	44.33	-29.93	17.21
2	94.00	2.05	-0.56	K5	45.13	-30.67	6.62
3	89.94	3.99	0.48	L5	45.80	-22.27	-8.26
4	83.96	4.13	-1.89	M5	43.63	-4.10	-17.23
5	79.43	3.22	-1.41	A8	57.85	10.96	-15.78
6	75.54	2.83	-1.13	B8	57.58	21.21	-8.35
7	71.39	1.07	-2.18	C8	57.64	27.69	0.73
8	66.86	1.92	-1.28	D8	56.62	25.70	4.95
9	62.79	-0.46	-1.56	E8	60.42	20.04	13.12
10	58.93	-0.52	-0.33	F8	65.39	8.16	18.23
11	53.99	-2.18	-1.63	G8	75.49	-1.76	21.54
12	49.68	-2.00	-0.67	H8	70.30	-17.67	19.90
13	45.49	-3.74	0.90	J8	66.70	-31.22	10.23
14	40.48	-2.83	3.57	K8	63.51	-32.13	3.43
15	35.32	-2.69	4.39	L8	63.96	-22.58	-12.73
16	29.88	-1.74	7.47	M8	63.59	-1.07	-13.99
17	24.50	-0.63	5.94	A15	96.95	-0.32	-1.24
18	21.42	-0.10	3.44	B15	91.60	2.36	1.06
19	20.33	0.17	0.45	C15	83.00	3.62	-0.80
20	18.62	-2.39	-2.56	D15	75.93	3.19	-0.85
A4	39.34	18.85	-33.69	E15	67.96	2.32	-1.23
B4	40.83	41.97	-17.15	F15	60.55	-1.40	-2.49
C4	44.37	50.41	-1.92	G15	53.63	-1.85	-0.12
D4	43.15	45.96	27.19	H15	44.59	-2.46	1.66
E4	45.07	43.64	35.78	J15	36.51	-2.88	6.56
F4	41.80	19.94	32.56	K15	25.79	-0.26	8.12
G4	52.49	-10.34	40.18	L15	20.42	2.55	1.66
H4	54.77	-36.14	34.68	M15	18.75	-2.17	-2.02
J4	47.61	-44.72	24.82	A19	48.96	13.02	18.81
K4	48.29	-42.36	8.40	B19	62.01	14.23	20.55
L4	47.79	-29.08	-14.86	C19	73.39	16.42	19.56
M4	45.22	-0.42	-36.63	D19	82.52	16.47	19.63
A5	37.37	7.85	-13.15	E19	49.04	19.08	18.75
B5	37.34	19.53	-7.05	F19	61.12	22.47	17.61
C5	38.20	25.95	2.81	G19	73.24	22.52	15.82
D5	37.04	22.86	12.23	H19	85.35	14.65	14.57
E5	41.42	13.92	19.45	J19	53.65	28.09	21.52
F5	42.05	3.20	23.44	K19	67.14	23.38	14.58
G5	52.24	-6.65	25.38	L19	73.16	24.85	13.05
H5	53.11	-24.44	20.77	M19	82.39	21.26	12.75

Separation Method: Adobe Photoshop,
80% GCR

Patch ID	L*	a*	b*	Patch ID	L*	a*	b*
1	97.20	0.38	-0.90	J5	44.16	-29.80	17.55
2	94.25	2.45	-0.20	K5	45.45	-31.03	7.27
3	89.93	4.11	0.63	L5	46.40	-21.84	-8.53
4	84.55	4.43	-1.83	M5	44.15	-3.46	-17.34
5	80.36	3.88	-0.91	A8	58.41	11.32	-15.15
6	76.20	3.25	-1.06	B8	57.65	21.63	-8.06
7	71.93	1.83	-1.41	C8	57.59	28.56	0.95
8	67.52	2.85	-1.18	D8	56.53	26.36	5.15
9	63.62	0.28	-1.38	E8	60.51	20.47	13.07
10	59.96	0.14	-0.01	F8	65.69	8.48	18.66
11	54.63	-0.77	-0.97	G8	75.81	-1.22	21.44
12	50.86	-1.18	0.40	H8	71.11	-17.86	20.20
13	46.78	-2.19	0.91	J8	66.59	-30.03	9.99
14	42.11	-1.30	2.13	K8	63.57	-31.78	3.30
15	37.27	-1.92	1.37	L8	64.61	-22.75	-13.02
16	31.58	-1.41	2.09	M8	63.99	-0.41	-14.41
17	25.82	-0.57	1.07	A15	96.82	0.26	-0.92
18	20.35	-0.66	-0.55	B15	91.55	3.00	0.82
19	16.98	-0.57	-1.28	C15	83.93	3.98	-0.69
20	14.58	-2.05	-1.54	D15	76.74	3.75	-0.53
A4	39.26	18.60	-32.76	E15	68.98	2.96	-1.05
B4	40.69	42.20	-13.97	F15	61.15	-0.29	-2.03
C4	44.09	52.05	-2.07	G15	54.69	-1.12	0.48
D4	43.27	46.35	26.82	H15	46.86	-1.61	1.62
E4	44.90	43.64	36.83	J15	39.95	-2.25	2.96
F4	41.32	19.88	32.55	K15	28.77	-0.36	2.25
G4	52.40	-10.72	40.34	L15	18.77	0.32	-1.11
H4	55.02	-36.70	35.25	M15	14.13	-2.05	-1.47
J4	48.21	-45.73	25.87	A19	49.32	13.56	18.47
K4	48.92	-42.59	7.95	B19	61.28	16.58	20.38
L4	48.62	-29.01	-14.72	C19	73.12	17.83	18.98
M4	45.21	-0.74	-35.39	D19	82.40	17.52	19.46
A5	37.90	7.76	-12.42	E19	48.24	20.34	18.27
B5	37.50	18.78	-6.78	F19	61.46	22.81	17.61
C5	37.86	26.60	1.59	G19	72.98	23.60	15.74
D5	36.76	26.60	1.59	H19	84.97	15.68	13.97
E5	41.38	14.40	19.19	J19	53.45	29.36	21.06
F5	42.75	2.45	19.26	K19	66.46	25.73	14.00
G5	53.02	-6.81	25.75	L19	72.25	27.00	12.35
H5	53.34	-24.98	20.34	M19	81.21	22.41	11.68

Separation Method: RIT Research,
0% GCR

Patch ID	L*	a*	b*	Patch ID	L*	a*	b*
1	96.74	0.78	0.57	J5	57.04	-28.32	17.50
2	95.40	2.30	0.39	K5	57.83	-26.41	3.94
3	92.17	2.04	-0.59	L5	59.49	-17.44	-8.48
4	89.08	1.80	-1.27	M5	58.65	-3.61	-14.04
5	86.61	1.48	-1.05	A8	71.52	6.77	-10.40
6	83.72	1.19	-1.00	B8	70.47	13.23	-4.74
7	80.89	0.02	-1.49	C8	70.49	17.37	1.57
8	77.64	0.50	-0.82	D8	69.76	15.96	4.81
9	74.37	-1.06	-1.45	E8	73.09	10.79	10.67
10	71.22	-1.76	-0.34	F8	76.56	2.82	14.51
11	67.07	-2.87	-1.42	G8	83.53	-2.37	14.52
12	63.55	-3.22	0.24	H8	79.72	-12.20	13.28
13	60.26	-4.62	1.01	J8	76.81	-20.56	4.85
14	55.97	-4.24	3.89	K8	74.00	-22.34	-0.82
15	51.86	-5.26	6.39	L8	74.89	-14.54	-11.14
16	47.20	-5.82	12.03	M8	75.15	-0.97	-9.59
17	41.75	-6.35	15.12	A15	96.88	0.65	-1.16
18	36.24	-5.10	11.27	B15	93.22	1.57	-0.65
19	33.21	-5.23	10.06	C15	88.54	1.62	-1.06
20	29.44	-1.06	2.38	D15	84.14	1.46	-1.02
A4	57.01	16.60	-23.87	E15	78.88	0.41	-1.50
B4	54.92	32.96	-10.94	F15	72.30	-1.96	-2.65
C4	55.58	42.22	-1.39	G15	66.57	-2.82	-0.14
D4	54.44	36.94	23.46	H15	59.07	-4.08	1.37
E4	56.89	32.30	43.26	J15	52.32	-5.86	8.61
F4	55.97	8.59	42.62	K15	43.82	-5.44	16.46
G4	63.82	-15.75	48.92	L15	34.65	2.24	12.43
H4	65.50	-34.96	43.84	M15	29.42	-1.04	-1.80
J4	58.29	-45.02	31.93	A19	62.89	6.20	18.00
K5	59.86	-35.59	2.68	B19	73.40	8.14	16.89
L5	60.96	-22.37	-15.54	C19	82.35	8.21	13.90
M5	62.22	-1.58	-28.25	D19	89.31	10.17	13.19
A5	53.45	3.80	-11.01	E19	62.98	11.06	17.44
B5	52.92	12.54	-5.06	F19	73.89	11.99	14.27
C5	53.02	17.42	3.04	G19	82.55	12.31	11.38
D5	52.04	14.26	13.95	H19	90.66	9.48	9.91
E5	56.62	5.31	20.01	J19	66.59	18.07	19.05
F5	56.60	5.31	20.01	K19	77.64	13.86	11.03
G5	64.83	-9.37	23.29	L19	82.40	14.90	9.21
H5	65.04	-21.77	17.79	M19	88.14	13.47	8.36

Separation Method: RIT Research,
50% GCR

Patch ID	L*	a*	b*
1	96.74	0.58	-0.65
2	93.95	1.99	-0.29
3	90.38	1.52	-0.43
4	86.55	1.78	-1.72
5	84.05	1.31	-1.31
6	81.73	1.25	-1.46
7	79.63	0.25	-1.91
8	76.63	1.09	-1.34
9	74.08	-0.28	-1.62
10	71.10	-0.73	-0.66
11	67.07	-1.81	-2.23
12	64.15	-1.41	-0.69
13	60.95	-2.87	0.00
14	57.34	-2.63	1.63
15	52.72	-3.62	2.86
16	47.85	-3.18	7.66
17	42.72	-2.52	9.77
18	37.91	-1.79	7.21
19	34.72	-0.03	4.99
20	32.06	-1.22	-2.76
A4	57.05	16.57	-23.78
B4	55.45	32.15	-10.48
C4	55.85	40.55	-1.32
D4	54.15	36.74	22.66
E4	56.28	32.18	41.74
F4	57.19	9.94	45.50
G4	64.99	-14.19	49.30
H4	64.67	-34.06	42.20
J4	57.67	-43.29	30.60
K4	59.37	-33.74	2.11
L4	61.07	-21.12	-15.20
M4	62.06	-1.52	-28.30
A5	55.42	4.47	-10.16
B5	54.96	13.34	-4.37
C5	54.69	18.83	2.64
D5	53.56	15.93	12.44
E5	57.92	7.03	20.38
F5	58.22	-2.08	25.22
G5	66.19	-8.00	22.96
H5	65.14	-20.44	17.00

Patch ID	L*	a*	b*
J5	57.78	-26.21	16.30
K5	58.45	-24.81	3.45
L5	60.12	-16.49	-9.81
M5	59.93	-3.32	-13.66
A8	71.59	5.92	-9.63
B8	70.82	12.62	-4.55
C8	70.58	16.38	1.01
D8	69.97	15.23	3.87
E8	72.82	10.45	9.76
F8	75.92	2.69	13.18
G8	81.86	-2.30	12.44
H8	78.16	-11.73	12.42
J8	75.48	-20.48	4.81
K8	72.84	-21.53	-1.29
L8	73.82	-13.96	-10.95
M8	74.54	-0.90	-9.30
A15	96.97	0.63	-1.02
B15	91.52	1.16	-0.55
C15	86.13	1.48	-1.23
D15	82.37	1.40	-1.12
E15	77.59	1.00	-1.42
F15	72.58	-1.09	-2.38
G15	67.91	-1.76	-0.44
H15	61.17	-2.67	0.73
J15	54.42	-4.27	5.65
K15	45.41	-2.22	13.05
L15	36.88	1.61	9.62
M15	32.72	-2.00	-3.09
A19	64.87	6.13	16.04
B19	73.86	7.46	12.53
C19	80.93	8.29	9.72
D19	89.39	10.40	11.05
E19	64.11	10.85	15.04
F19	73.32	11.79	9.79
G19	81.46	11.97	9.79
H19	90.83	9.96	6.04
J19	66.57	17.55	14.57
K19	76.23	13.46	7.41
L19	81.14	14.45	6.90
M19	88.05	13.76	6.48

Separation Method: RIT Research,
80% GCR

Patch ID	L*	a*	b*	Patch ID	L*	a*	b*
1	97.32	0.67	-0.37	J5	57.80	-24.96	14.99
2	95.05	2.05	0.46	K5	58.77	-23.49	2.83
3	90.57	1.82	0.20	L5	60.29	-15.37	-9.45
4	86.94	1.98	-1.82	M5	60.22	-2.57	-12.71
5	84.34	1.76	-1.52	A8	71.23	6.99	-10.21
6	82.18	1.76	-1.18	B8	70.58	12.88	-4.76
7	79.42	0.77	-1.92	C8	70.40	16.91	1.55
8	76.33	1.15	-1.57	D8	69.83	15.88	3.94
9	73.51	0.11	-1.82	E8	72.99	11.20	9.77
10	70.48	-0.07	-0.79	F8	75.79	3.69	12.11
11	67.01	-0.97	-1.68	G8	82.24	-1.56	13.02
12	63.81	-1.09	-0.92	H8	78.86	-12.17	12.19
13	60.69	-1.94	-0.14	J8	76.96	-21.18	4.58
14	56.91	-1.49	1.78	K8	74.12	-22.06	1.15
15	52.42	-2.42	2.77	L8	74.76	-14.00	10.52
16	48.57	-2.46	6.90	M8	74.73	-0.33	-9.48
17	43.36	-1.67	8.18	A15	97.52	0.89	-0.70
18	37.80	-3.08	8.06	B15	92.17	1.21	-0.69
19	34.54	0.41	5.01	C15	86.72	1.78	-0.90
20	31.16	-0.79	-2.16	D15	82.52	2.18	-0.74
A4	57.01	16.75	-23.54	E15	77.63	1.45	-1.55
B4	55.88	32.14	-10.27	F15	71.90	-0.36	-0.26
C4	56.00	40.06	-1.22	G15	66.79	-0.82	-0.80
D4	54.73	36.21	20.19	H15	60.10	-1.64	0.49
E4	56.92	32.15	40.12	J15	53.09	-2.86	5.24
F4	56.64	9.96	45.31	K15	45.06	-0.90	10.66
G4	64.26	-12.57	46.83	L15	36.17	2.58	7.30
H4	65.83	-34.75	42.27	M15	30.76	-1.25	-2.65
J4	58.34	-43.37	29.83	A19	63.42	7.04	15.85
K4	60.31	-3.34	2.74	B19	73.03	8.42	14.05
L4	61.08	-2.01	-15.05	C19	81.29	9.23	13.00
M4	62.09	-1.27	28.02	D19	88.52	10.77	12.62
A5	54.71	5.17	-9.43	E19	63.01	11.95	14.06
B5	54.33	13.79	-4.52	F19	73.11	12.42	12.55
C5	53.71	19.12	2.33	G19	81.86	13.16	11.06
D5	52.95	16.17	10.73	H19	90.45	9.66	9.52
E5	57.63	7.28	18.91	J19	66.38	18.32	16.85
F5	57.74	-1.06	22.54	K19	77.35	14.64	10.15
G5	65.03	-6.80	20.59	L19	81.60	15.57	9.31
H5	65.45	-19.47	16.41	M19	87.97	13.76	8.16

Appendix B

Calculated Color Differences

The following pages contain the calculated color differences, expressed in ΔE*, between each separation method and the non-GCR separation method for each system. Each page lists all 80 patches measured and the ΔE* value for each patch represents the color difference between that patch and the corresponding patch of the non-GCR output.

Separation Method: Hell Scanner, UCA Off, 50% GCR

Patch ID	ΔE*	Patch ID	ΔE*
1	0.99	J5	9.79
2	1.67	K5	10.54
3	2.15	L5	5.86
4	3.53	M5	3.92
5	4.28	A8	1.79
6	4.28	B8	1.97
7	4.67	C8	3.60
8	5.20	D8	4.22
9	5.42	E8	5.67
10	4.95	F8	4.51
11	6.48	G8	5.90
12	6.04	H8	5.92
13	5.80	J8	4.58
14	4.73	K8	4.10
15	5.85	L8	4.45
16	4.73	M8	1.39
17	5.21	A15	3.75
18	5.49	B15	5.13
19	5.74	C15	5.35
20	2.40	D15	5.20
A4	1.42	E15	4.69
B4	5.06	F15	5.68
C4	6.17	G15	5.07
D4	6.70	H15	3.92
E4	7.81	J15	4.27
F4	6.45	K15	5.22
G4	4.59	L15	3.19
H4	6.01	M15	2.79
J4	10.27	A19	7.71
K4	11.08	B19	6.47
L4	2.91	C19	4.27
M4	1.50	D19	1.05
A5	4.35	E19	4.53
B5	5.35	F19	3.53
C5	5.88	G19	2.00
D5	6.54	H19	1.42
E5	6.87	J19	4.55
F5	7.46	K19	3.39
G5	6.40	L19	1.95
H5	7.00	M19	0.69

Separation Method: Hell Scanner, UCA Off, 80% GCR

Patch ID	ΔE*	Patch ID	ΔE*
1	2.12	J5	12.02
2	3.25	K5	13.25
3	3.97	L5	7.53
4	4.77	M5	3.35
5	6.59	A8	2.37
6	6.84	B8	4.97
7	7.75	C8	7.46
8	7.69	D8	8.62
9	8.61	E8	10.60
10	8.43	F8	8.02
11	9.05	G8	10.61
12	8.83	H8	9.62
13	7.50	J8	8.12
14	7.27	K8	6.00
15	7.16	L8	3.98
16	5.98	M8	5.63
17	5.47	A15	5.09
18	4.52	B15	7.20
19	4.01	C15	7.62
20	4.31	D15	7.50
A4	1.08	E15	7.15
B4	5.85	F15	7.96
C4	7.44	G15	7.38
D4	9.54	H15	4.16
E4	9.26	J15	4.50
F4	7.48	K15	5.03
G4	5.84	L15	4.35
H4	8.15	M15	4.42
J4	12.47	A19	12.07
K4	14.58	B19	10.50
L4	4.85	C19	6.99
M4	1.05	D19	3.03
A5	5.38	E19	8.34
B5	6.96	F19	6.19
C5	9.25	G19	4.17
D5	8.58	H19	3.01
E5	9.61	J19	7.55
F5	9.43	K19	5.00
G5	9.49	L19	3.57
H5	7.70	M19	1.37

Separation Method: Hell Scanner, UCA On, 50% GCR

Patch ID	ΔE*	Patch ID	ΔE*
1	1.12	J5	9.34
2	0.96	K5	9.31
3	1.29	L5	5.01
4	2.07	M5	3.01
5	3.43	A8	2.17
6	3.53	B8	1.24
7	3.97	C8	3.03
8	3.58	D8	3.84
9	3.42	E8	3.23
10	3.34	F8	2.72
11	4.73	G8	3.94
12	4.44	H8	2.31
13	4.67	J8	2.81
14	4.93	K8	1.85
15	4.00	L8	3.81
16	2.62	M8	2.03
17	3.05	A15	3.57
18	4.73	B15	4.34
19	4.45	C15	5.86
20	2.06	D15	5.40
A4	2.65	E15	4.72
B4	5.03	F15	5.16
C4	6.40	G15	2.97
D4	6.59	H15	3.68
E4	7.55	J15	3.60
F4	5.27	K15	5.00
G4	3.97	L15	1.69
H4	7.03	M15	2.65
J4	11.45	A19	5.90
K4	10.95	B19	5.46
L4	3.96	C19	4.39
M4	1.46	D19	2.16
A5	2.88	E19	5.50
B5	5.68	F19	4.19
C5	7.14	G19	1.97
D5	6.56	H19	1.32
E5	6.28	J19	3.93
F5	5.22	K19	2.33
G5	4.73	L19	1.27
H5	6.14	M19	1.23

Separation Method: Hell Scanner, UCA On, 80% GCR

Patch ID	ΔE*	Patch ID	ΔE*
1	0.84	J5	11.60
2	0.87	K5	10.97
3	2.62	L5	5.97
4	4.01	M5	3.58
5	6.03	A8	2.48
6	5.71	B8	3.04
7	7.37	C8	4.62
8	6.73	D8	6.37
9	6.35	E8	6.06
10	6.90	F8	5.89
11	7.45	G8	6.71
12	7.13	H8	6.78
13	8.45	J8	7.51
14	8.62	K8	7.90
15	9.00	L8	8.40
16	8.69	M8	1.22
17	8.83	A15	3.61
18	9.04	B15	5.69
19	8.22	C15	6.19
20	3.15	D15	6.84
A4	1.39	E15	5.57
B4	5.44	F15	6.66
C4	7.94	G15	3.92
D4	8.67	H15	2.76
E4	8.39	J15	3.40
F4	7.05	K15	5.88
G4	4.47	L15	1.89
H4	8.87	M15	3.67
J4	12.19	A19	8.27
K4	12.69	B19	6.07
L4	4.67	C19	4.74
M4	6.83	D19	2.25
A5	5.73	E19	7.03
B5	7.53	F19	6.15
C5	9.49	G19	3.87
D5	8.80	H19	2.02
E5	8.16	J19	5.69
F5	7.34	K19	2.96
G5	6.75	L19	2.44
H5	6.58	M19	1.70

Separation Method: Adobe PhotoShop, 50% GCR

Patch ID	ΔE*	Patch ID	ΔE*
1	2.87	J5	1.37
2	0.75	K5	0.91
3	0.93	L5	1.49
4	0.40	M5	0.47
5	0.41	A8	0.44
6	0.61	B8	0.49
7	0.86	C8	0.28
8	1.36	D8	0.42
9	1.73	E8	0.94
10	2.69	F8	1.64
11	1.74	G8	1.39
12	1.49	H8	1.29
13	1.27	J8	1.04
14	1.17	K8	1.00
15	0.57	L8	5.18
16	0.38	M8	9.89
17	2.48	A15	0.71
18	4.86	B15	1.09
19	6.86	C15	0.70
20	9.97	D15	1.11
A4	0.65	E15	0.89
B4	0.79	F15	1.26
C4	1.15	G15	0.45
D4	1.04	H15	1.32
E4	1.67	J15	0.64
F4	3.36	K15	0.39
G4	4.65	L15	0.18
H4	1.30	M15	1.51
J4	1.55	A19	1.94
K4	0.84	B19	3.38
L4	0.66	C19	1.19
M4	1.26	D19	0.57
A5	0.87	E19	2.00
B5	1.16	F19	0.96
C5	0.83	G19	0.51
D5	1.31	H19	0.65
E5	0.82	J19	1.25
F5	0.53	K19	2.61
G5	1.50	L19	1.92
H5	0.99	M19	1.96

Separation Method: Adobe PhotoShop, 80% GCR

Patch ID	ΔE*	Patch ID	ΔE*
1	0.79	J5	1.06
2	1.33	K5	1.09
3	1.06	L5	2.03
4	0.99	M5	1.20
5	1.63	A8	0.41
6	1.28	B8	0.65
7	1.98	C8	1.12
8	2.18	D8	1.34
9	2.80	E8	1.95
10	3.92	F8	2.19
11	3.05	G8	2.61
12	2.71	H8	3.33
13	2.56	J8	5.26
14	2.52	K8	5.86
15	3.98	L8	3.64
16	5.70	M8	5.28
17	3.82	A15	1.42
18	3.46	B15	1.31
19	3.49	C15	1.48
20	5.92	D15	1.39
A4	1.60	E15	0.81
B4	3.41	F15	11.45
C4	2.23	G15	0.70
D4	1.53	H15	2.09
E4	2.53	J15	0.65
F4	3.36	K15	0.48
G4	4.95	L15	0.84
H4	2.13	M15	2.14
J4	3.06	A19	1.98
K4	1.49	B19	1.09
L4	1.26	C19	0.76
M4	2.53	D19	0.63
A5	1.39	E19	0.65
B5	1.06	F19	1.08
C5	1.81	G19	0.73
D5	2.45	H19	0.83
E5	0.52	J19	1.07
F5	4.07	K19	0.62
G5	2.32	L19	0.79
H5	1.72	M19	0.37

Separation Method: RIT Research Corporation, 50% GCR

Patch ID	ΔE*
1	0.22
2	1.63
3	1.68
4	2.57
5	2.58
6	2.04
7	1.35
8	1.28
9	0.85
10	1.09
11	1.33
12	2.12
13	2.14
14	3.09
15	3.99
16	5.15
17	6.65
18	5.50
19	7.42
20	5.77
A4	0.10
B4	1.07
C4	1.69
D4	0.87
E4	1.64
F4	3.41
G4	1.99
H4	2.05
J4	2.27
K4	2.00
L4	1.30
M4	0.18
A5	2.25
B5	2.30
C5	2.22
D5	2.72
E5	2.19
F5	2.41
G5	1.96
H5	1.55
J5	2.54
K5	1.78
L5	1.75
M5	1.37
A8	0.20
B8	1.75
C8	2.42
D8	1.77
E8	1.42
F8	0.95
G8	1.73
H8	2.61
J8	3.96
K8	4.95
L8	5.26
M8	3.56
A15	1.15
B15	0.73
C15	1.14
D15	1.21
E15	1.01
F15	1.48
G15	2.67
H15	1.84
J15	1.33
K15	1.49
L15	1.23
M15	0.68
A19	2.79
B19	4.44
C19	4.42
D19	2.15
E19	2.66
F19	4.52
G19	3.30
H19	3.90
J19	4.51
K19	3.91
L19	2.67
M19	1.90

Separation Method: RIT Research Corporation, 80% GCR

Patch ID	ΔE*
1	0.62
2	0.42
3	1.80
4	2.22
5	2.34
6	1.65
7	1.71
8	1.64
9	1.50
10	1.90
11	1.92
12	2.44
13	2.95
14	3.59
15	4.64
16	6.28
17	8.52
18	4.10
19	7.69
20	4.86
A4	0.36
B4	1.43
C4	2.21
D4	3.36
E4	3.14
F4	3.09
G4	3.83
H4	1.62
J4	2.67
K4	2.24
L4	2.33
M4	0.41
A5	2.44
B5	1.96
C5	1.97
D5	3.85
E5	2.47
F5	4.66
G5	3.73
H5	2.71

Patch ID	ΔE*
J5	4.26
K5	3.26
L5	2.42
M5	2.31
A8	0.86
B8	1.11
C8	1.83
D8	1.79
E8	1.63
F8	2.90
G8	2.12
H8	2.79
J8	4.58
K8	7.47
L8	7.20
M8	1.63
A15	0.41
B15	0.37
C15	0.47
D15	0.88
E15	0.99
F15	2.67
G15	2.14
H15	1.39
J15	0.69
K15	1.99
L15	0.83
M15	0.77
A19	2.37
B19	2.88
C19	1.72
D19	1.14
E19	3.50
F19	1.94
G19	1.14
H19	0.48
J19	2.22
K19	1.21
L19	1.05
M19	0.39

Appendix C

Results of ANOVA Analyses

The following pages contain the full results of each ANOVA test. Each page contains a separate and complete comparison of sample populations.

Single-Factor ANOVA for all Separation Methods at 50% GCR

Summary Statistics

Groups	Count	Sum	Average	Variance
Hell UCA Off	80	383.46	4.79	4.60
Hell UCA On	80	331.29	4.14	4.60
Adobe Photoshop	80	127.75	1.60	3.14
RIT Research	80	189.77	2.37	2.24

ANOVA Results

Source of Variation	SS	df	MS	F-value	p-value	F-critical
Between Groups	534.18	3	178.06	48.86	5.708E-26	2.63
Within Groups	1151.55	316	3.64			
Total	1685.73	319				

Single-Factor ANOVA for all Separation Methods at 80% GCR

Summary Statistics

Groups	Count	Sum	Average	Variance
Hell UCA Off	80	544.42	6.81	7.78
Hell UCA On	80	483.36	6.04	7.01
Adobe Photoshop	80	164.94	2.06	1.91
RIT Research	80	195.09	2.44	2.98

ANOVA Results

Source of Variation	SS	df	MS	F-value	p-value	F-critical
Between Groups	1422.38	3	474.13	96.29	2.76E-44	2.63
Within Groups	1555.92	316	4.92			
Total	2978.30	319				

Single-Factor ANOVA for Separations Made on the Hell Scanner at 50% and 80% GCR with UCA On

Summary Statistics

Groups	Count	Sum	Average	Variance
Hell-UCA On-50% GCR	80	331.29	4.14	4.60
Hell-UCA On-80% GCR	80	483.36	6.04	7.01

ANOVA Results

Source of Variation	SS	df	MS	F-value	p-value	F-critical
Between Groups	144.53	1	144.53	24.90	1.58E-06	3.90
Within Groups	917.17	158	5.80			
Total	1061.69	159				

Single-Factor ANOVA for Separations Made on the Hell Scanner at 50% and 80% GCR with No UCA

Summary Statistics

Groups	Count	Sum	Average	Variance
Hell-No UCA-50% GCR	80	383.46	4.79	4.60
Hell-No UCA-80% GCR	80	544.42	6.81	7.78

ANOVA Results

Source of Variation	SS	df	MS	F-value	p-value	F-critical
Between Groups	161.92	1	161.92	26.14	9.064E-07	3.90
Within Groups	978.57	158	6.19			
Total	1140.48	159				

Single-Factor ANOVA for Separations Made with Adobe Photoshop at 50% and 80% GCR

Summary Statistics

Groups	Count	Sum	Average	Variance
Photoshop 50% GCR	80	127.75	1.60	3.14
Photoshop 80% GCR	80	164.94	2.06	1.91

ANOVA Results

Source of Variation	SS	df	MS	F-value	p-value	F-critical
Between Groups	8.65	1	8.65	3.43	0.07	3.90
Within Groups	398.92	158	2.52			
Total	407.57	159				

Single-Factor ANOVA for Separations Made with RIT Research Corporation's RGB-CMYK Transform at 50% and 80% GCR

Summary Statistics

Groups	Count	Sum	Average	Variance
RIT Research 50% GCR	80	189.77	2.37	2.24
RIT Research 80% GCR	80	195.09	2.44	2.98

ANOVA Results

Source of Variation	SS	df	MS	F-value	p-value	F-critical
Between Groups	0.18	1	0.18	0.07	0.80	3.90
Within Groups	412.82	158	2.61			
Total	413.00	159				

Single-Factor ANOVA Comparing Separations Made with the Hell Scanner and the Desktop Systems at 50% GCR

Summary Statistics

Groups	Count	Sum	Average	Variance
Hell Scanner 50% GCR	160	714.76	4.47	4.68
Desktop Systems 50% GCR	160	317.52	1.98	2.82

ANOVA Results

Source of Variation	SS	df	MS	F-value	p-value	F-critical
Between Groups	493.12	1	493.12	131.49	1.042E-25	3.87
Within Groups	1192.60	318	3.75			
Total	1685.73	319				

Single-Factor ANOVA Comparing Separations Made with the Hell Scanner and the Desktop Systems at 80% GCR

Summary Statistics

Groups	Count	Sum	Average	Variance
Hell Scanner 80% GCR	160	1027.78	6.42	7.50
Desktop Systems 80% GCR	160	360.03	2.25	2.47

ANOVA Results

Source of Variation	SS	df	MS	F-value	p-value	F-critical
Between Groups	1393.40	1	1393.40	279.58	1.791E-45	3.87
Within Groups	1584.90	318	4.98			
Total	2978.30	319				

Single-Factor ANOVA for Separations Made Using Adobe Photoshop and RIT Research Corporation's RGB-CMYK Transform at 50% GCR

Summary Statistics

Groups	Count	Sum	Average	Variance
Adobe Photoshop 50% GCR	80	127.75	1.60	3.14
RIT Research 50% GCR	80	189.77	2.37	2.24

ANOVA Results

Source of Variation	SS	df	MS	F-value	p-value	F-critical
Between Groups	24.04	1	24.04	8.94	0.003	3.90
Within Groups	424.91	158	2.69			
Total	448.95	159				

Single-Factor ANOVA for Separations Made Using Adobe Photoshop and RIT Research Corporation's RGB-CMYK Transform at 80% GCR

Summary Statistics

Groups	Count	Sum	Average	Variance
Adobe Photoshop 80% GCR	80	164.94	2.06	1.91
RIT Research 80% GCR	80	195.09	2.44	2.98

ANOVA Results

Source of Variation	SS	df	MS	F-value	p-value	F-critical
Between Groups	5.68	1	5.68	2.32	0.13	3.90
Within Groups	386.83	158	2.45			
Total	392.51	159				

Single-Factor ANOVA Comparing Separations Made on the Hell Scanner at 50% GCR with UCA Off and UCA On

Summary Statistics

Groups	Count	Sum	Average	Variance
50% GCR UCA Off	80	383.46	4.79	4.60
50% GCR UCA On	80	331.29	4.14	4.60

ANOVA Results

Source of Variation	SS	df	MS	F-value	p-value	F-critical
Between Groups	17.01	1	17.01	3.70	0.0563	3.90
Within Groups	726.64	158	4.60			
Total	743.65	159				

Single-Factor ANOVA Comparing Separations Made on the Hell Scanner at 80% GCR with UCA Off and UCA On

Summary Statistics

Groups	Count	Sum	Average	Variance
80% GCR UCA Off	80	544.42	6.81	7.78
80% GCR UCA On	80	483.36	6.04	7.01

ANOVA Results

Source of Variation	SS	df	MS	F-value	p-value	F-critical
Between Groups	23.30	1	23.30	3.15	0.0779	3.90
Within Groups	1169.09	158	7.40			
Total	1192.39	159				